APPLICATION OF THE KALINA CYCLE® TO WASTE HEAT RECOVERY IN HAWAII

Final Report

Prepared for

State of Hawaii-
Department of Business, Economic Development and Tourism (DBEDT)

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1.0 EXECUTIVE SUMMARY

Hawaii's unique geography and geology has allowed the development of a rather diverse energy portfolio. Still, in spite of its uniqueness, Hawaii maintains a predominantly fossil-fuel based energy economy (see Figure 2.1). With over 78% of its energy derived by petroleum generated electricity, 12% from coal and the remaining 10% from hydroelectric, geothermal, wind, etc., Hawaii has still not begun to realize its potential for embracing more environmentally friendly power generation technologies.

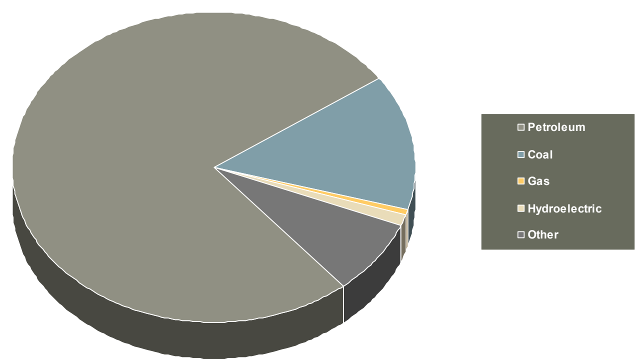


Figure 2.1 Energy Generation by Source, 1999
(*Courtesy: Energy Information Administration)*

The current state's energy portfolio is one burdened with significant environmental stresses (see Figure 2.2) deleterious to the pristine natural environment which is the basis of Hawaii's life-blood, tourism. One method of increasing energy production capacity to meet incremental demand is by harnessing energy currently "wasted" through inefficiencies of existing systems through an environmentally benign system such as the Kalina Cycle®.

1.1 Technical Objectives

The primary technical objective of this project is the identification and subsequent economic and technical evaluation of the Kalina Cycle® to waste heat recovery in the State of Hawaii. Implementing this innovative waste heat recovery system to pre-existing, suitable thermal resources (i.e., Ocean Thermal Energy Conversion (OTEC), bottoming cycle applications to waste heat recovery of fossil fuel, geothermal, biomass/waste, etc. power production facilities) to capture and produce additional electrical energy from previously ignored resources could provide significant economic benefits and reductions in associated energy emissions from current conventional practices. The purpose of this endeavor is to investigate the technical and economic feasibility of implementing such a system to harness Hawaii's existing thermal and waste heat resources. An evaluation of the potential costs and benefits of this integration is discussed along with a proposed marketing strategy with recommendations included for potential funding of such projects to encourage private sector development of this technology in Hawaii.

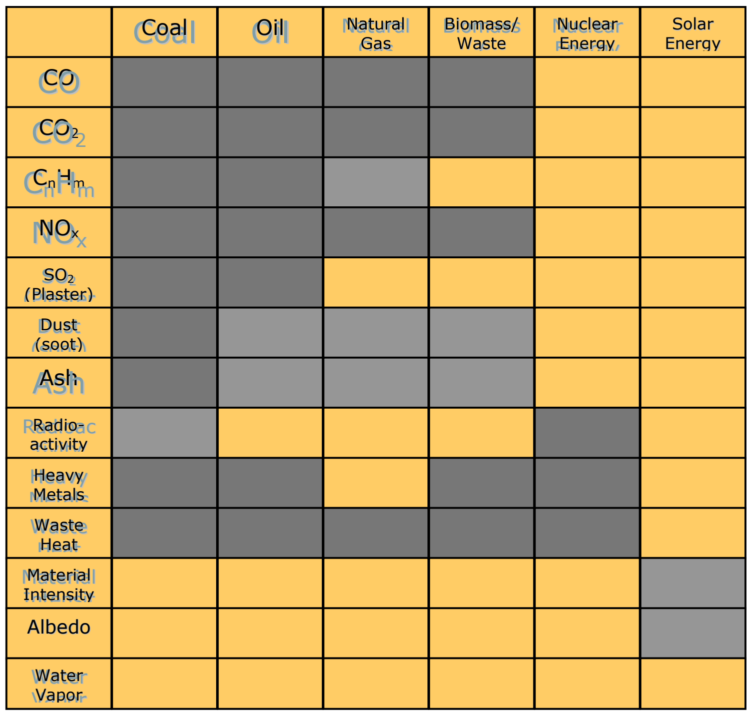


Figure 2.2: Residues/Pollutants/Effects (qualitative)
(Courtesy: Center for Solar Energy and Hydrogen Research)

1.2 Project Description

The Kalina Cycle® is a break-through technology which is a more efficient alternative to the traditional Rankine Cycle, the workhorse design of power plants world-wide since the mid-1800's. In the Rankine Cycle, water is converted into high pressure steam which drives a turbine. The steam is then condensed back into water and the process is repeated. Kalina Cycle® technology utilizes an ammonia/water mixture to produce vapor which drives a turbine. The mixture, which can be varied throughout the process, produces a vapor at a higher average temperature than the Rankine Cycle under similar conditions and rejects heat at a lower average temperature than the Rankine Cycle. Thus, the Kalina Cycle® results in more power for the same amount of fuel or thermal input. By making power plants more efficient, or by recovering waste heat or capturing naturally occurring thermal resources, the Kalina Cycle® reduces the cost of power and decreases resultant pollution emissions.

In December of 1991, Exergy Inc., the company which owns the fifteen (15) U.S. Patents protecting Kalina Cycle® technology, fired up the first ever Kalina Cycle® power plant at the U.S. Department of Energy's *Energy Technology & Engineering Center* near Canoga Park, California. The stand-alone three megawatt bottoming cycle proved that Exergy's Kalina Cycle® offered sizable gains in power plant efficiency. Soon after the switch was thrown, the Canoga Park plant began generating economical power for transmission to Southern California Edison's grid. The Canoga Park plant continued to operate successfully for five years and, in November 1996, it was converted into a fully operational 6.5 MW Kalina combined cycle power plant – the world's first.

Since the first implementation in Canoga Park several other installations harnessing waste heat from various sources, including bottoming cycles capturing waste heat from power plants, large manufacturing facilities and, most recently, a geothermal electrical generating facility in Husavik, Iceland have been constructed and continue to operate successfully with many other facilities still in the design phase. This project affords a unique opportunity to investigate the potential for implementing a Kalina Cycle® conversion system in Hawaii to harness one or more of the waste heat and naturally occurring thermal resources available in the Hawaiian Islands. This investigation is further encouraged by the operational success and energy availability experienced by currently operating Kalina Cycle® facilities across the globe combined with the potential economic and environmental benefits associated with this technology.

This report identifies and quantifies potential waste heat resources currently existing across the State of Hawaii which could directly benefit from integration of Kalina Cycle® technology to recover these thermal resources currently lost to the environment. The relative economic benefits of each proposed waste heat recovery application is discussed and the potential efficiency and financial gains afforded through this technology are also presented. Section 6 provides a preliminary design of a Kalina Cycle® OTEC facility provided by Recurrent Resources, LLC, the company which holds the patents for Kalina Cycle® technology. Envisioned marketing strategies and financing mechanisms for realizing the proposed systems is also provided.

1.3 Work Plan

The work plan for the *"Application of the Kalina Cycle® to Waste Heat Recovery in Hawaii"* effort approximated the following time schedule according to the description provided.

Task 1: Initially, it was necessary to identify potential waste heat sources available for exploitation via Kalina Cycle® technology. Once identified each potential source was characterized according to size/energy potential of available resource, source, thermal characteristics and potential for Kalina Cycle® application. Following this analysis a relative comparison of potential applications was performed according to the above criterion to determine the most promising applications for the Kalina Cycle® in Hawaii.

Task 2: An extensive literature search was performed in order to identify existing and proposed Kalina Cycle® applications currently operating or under consideration globally. From these existing facilities the most relevant and potentially advantageous applications for Kalina Cycle® technology according to previously identified thermal resources accomplished during *Task 1* was discerned. Potential applications at this stage of analysis included, but were not limited to, (1) potential integration into Ocean Thermal Energy Conversion (OTEC) designs; and (2) bottoming cycles for electricity-generating power plants (fossil fueled, geothermal, or biomass/waste).

Task 3: Following the literature search and identification of suitable Kalina Cycle® applications according to available waste heat resources readily available in Hawaii, economic analyses of the potential Kalina Cycle® applications was performed. Pricing considerations and estimates based upon available data for typical Kalina Cycle® conversion systems has been provided for each of the proposed suitable applications for Hawaii.

These economic analyses have incorporated estimates for (1) operating and maintenance costs of typical Kalina Cycle® conversion systems utilizing operational experience numbers procured from existing Kalina Cycle® facilities; (2) comparative life-cycle cost estimates of typical Kalina Cycle® systems; (3) break-even revenue requirements as well as anticipated revenues and rates of return projected for analyzed Kalina Cycle® waste heat applications. Finally, each candidate waste heat resource has been analyzed and prioritized according to economic and technological potential in order to further identify the most promising applications of Kalina Cycle® technology in Hawaii to provide a foundation for further technical and economic analysis.

Task 4: After identifying the most promising Kalina Cycle® applications for waste heat recovery here in Hawaii as outlined in Task 3, a preliminary design for a Kalina Cycle® system was performed for this potential waste heat recovery application (see Section 6). Major system components and subsystems necessary for successful integration of Kalina Cycle® OTEC technology into the available waste heat resource recovery have been identified and necessarily integrated into the design.

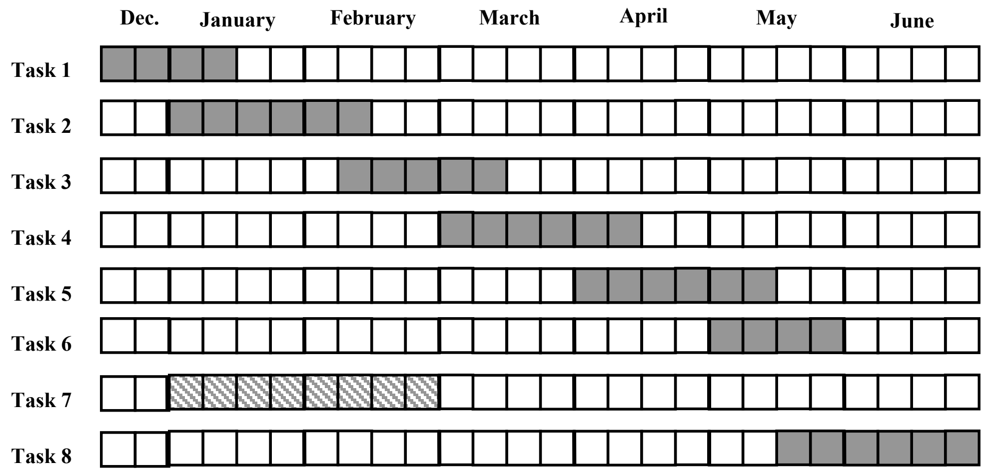
Task 5: A marketing strategy has been developed utilizing the economic and technical data established in *Tasks 3* and *4*, respectively. The marketing plan was developed to foster and support interest in private sector development of three of the previously identified most feasible Kalina Cycle® Conversion Systems.

Task 6: In order to further support potential private sector development of the Kalina Cycle® Conversion Systems in Hawaii, an effort has been made to identify and outline potential financing mechanisms suitable for the economic and successful integration of this technology into the framework of Hawaii's existing energy policy.

Task 7: As per **RFQP-03-10-ERT / State of Hawaii**, OCEES personnel participated in the "*Innovative Energy Systems Workshop"* held in March, 2003 in Honolulu with two presentations outlining the preliminary results accumulated up to that point along with on-going commercialization efforts of Kalina Cycle® technology. Likewise, two OCEES' principals served as panel members and topic experts during the Workshop. Information relevant to the proposed topic has been accumulated, collated and summarized in Appendix A of this report.

Task 8: Completion of duties for this project will be realized upon submission of the Final Report incorporating comments and recommendations obtained through the DBEDT Project Manager. As per RFQP requirements, three (3) hard copies and a reproducible master of the final report along with fifty (50) additional copies in electronic format (CD-ROM) will be produced and submitted to DBEDT on or before June 30, 2003.

Approximate Work Plan
(December 16, 2002 thru June 30, 2003)



Task 1: Identify Various Waste Heat Resources in Hawaii
Task 2: Conduct Literature Search of Various Applications of Kalina Cycle®
Task 3: Perform Economic Analysis for Kalina Cycle® Waste Heat Systems
Task 4: Develop Preliminary Design of Typical Kalina Cycle® System
Task 5: Develop Marketing Plan for Kalina Cycle® System Development in Hawaii
Task 6: Identify Possible Financing Mechanisms for Kalina Cycle® Systems in Hawaii
Task 7: Present and Participate in "Innovative Energy Systems Workshop"
Task 8: Prepare and Submit Final Report

1.4 Findings/Conclusions

From the information compiled during this project, several relevant conclusions for the potential of waste heat recovery via the Kalina Cycle® in Hawaii can be drawn. Specifically:

- The waste heat resources available for potential exploitation are significant.
- Three principal applications for Kalina Cycle® waste heat recovery stand out above other waste heat resources:
  - Ocean Thermal Energy Conversion (OTEC) – both land-based and shelf-mounted facilities.
  - Waste heat recovery from geothermal brine from Puna Geothermal power facility on the Big Island.
  - Bottoming cycle applications to existing fossil and bio-fuel based power plants across the state.

- Although land-based OTEC systems are not currently cost competitive from a power production standpoint alone; integrated, multi-product systems can be shown to be economically viable.
- Off-shore platform OTEC facilities of ≥100 MW capacity are economically and technologically viable for integration into Hawaii's energy portfolio, today. They also hold the greatest potential contribution of any renewable to address Hawaii's desire to realize a 20% renewable energy generation capacity over the next decade.
- The Puna Geothermal power facility is perhaps the best waste heat application for immediate consideration in Hawaii. Puna could realize an increase of 30 -40% over current generating capacity simply by integrating a very cost competitive Kalina Cycle® system to recover waste heat in currently unused brine. This increase in production can be realized simply by maximizing efficiency of existing resources.
- Fossil fuel based plants could benefit from addition of Kalina bottoming cycle plants capturing waste heat from the stack gas at larger facilities. Retrofitting the existing facilities should be possible considering that Kalina Cycle® process equipment can be suitably configured vertically to minimize space limitations currently hindering other bottoming cycle considerations.
- Kalina Cycle® technology is a very cost competitive technology to conventional systems when life cycle analysis is applied.
- The Kalina Cycle® has a very quick payoff period and a good return on investment (ROI) for many waste heat applications.
- The Kalina Cycle® has very low operational and maintenance costs with no deleterious environmental effects.

1.5 Recommendations

Although preliminary in nature and limited in qualitative analysis, this report has identified several waste heat resources which could benefit greatly in efficiency through increased power production by implementing Kalina Cycle® technology. The following recommendations help identify the next steps to accomplishing these gains.

- The most immediately promising potential application within the state is adding a Kalina Cycle® facility to the Puna Geothermal plant. A more detailed study of the resource availability, potential Kalina Cycle® configuration, costing and site specific criteria is definitely warranted. This particular application makes very good economic sense, especially in light of the planned capacity increase. If properly designed and incorporated in the expansion design phase, the Puna plant could very well provide a significant portion of the Big Island's total energy production through integration of the Kalina Cycle® (> 80 MW).

- The small diesel facilities on Lanai and Molokai warrant further consideration for integrating a Kalina bottoming cycle facility to increase existing system capacity to meet increasing incremental demands. A quick analysis developed by Recurrent Resources, LLC, the company which holds the patents for the Kalina Cycle®, suggests that these facilities warrant further consideration for Kalina Cycle® integration (see Section 5.3).
- A prototype Kalina Cycle OTEC system, utilizing the existing 55" cold water pipe recently deployed off NELHA could assist in proving the applicability of the Kalina Cycle to OTEC technology as well as provide a cost savings to NELHA by providing the necessary electricity to operate the entire facility at a reduced rate in comparison to that currently provided by HELCO. This plant was proposed by a private company in conjunction with Exergy (now Recurrent Resources, LLC) in 2000. A re-evaluation of that proposal is warranted in light of the enormous potential OTEC possesses to meet Hawaii's current and future energy needs.
- A serious investigation into the potential for implementing a public-private venture to develop an off-shore floating OTEC plant (100 MW) should be initiated in order to provide the groundwork necessary to effect the development of such a facility within the State of Hawaii in order to reach the government's goals of 20% renewable energy generation capacity within the state's energy portfolio within the next decade.

2.0 INTRODUCTION

The State of Hawaii – Department of Business and Economic Development and Tourism (DBEDT) has commissioned a study of the potential within the state of Hawaii for waste heat recovery via a relatively new bottoming cycle technology referred to as the Kalina Cycle®. Power production utilizing the Kalina Cycle® technology can cost effectively increase power production from existing waste heat resources and power generating facilities without adding greenhouse gas emissions or other deleterious environmental consequences. Once installed, the Kalina Cycle® does not require additional expenditures or budgetary concerns for fuel purchase as the system derives its power generating potential from existing waste heat resources. The Kalina Cycle® holds the potential of providing additional environmentally responsible energy sales revenues to existing power production facilities across the state with modest levels of investment on the part of the utility owner. This report investigates the extent of the potential existing in Hawaii for application of this technology.

2.1 The Kalina Cycle®

The Kalina Cycle® is a new thermal cycle for energy conversion for electric power generation which was developed and patented by Exergy, Inc. (now Recurrent Resources, LLC), a U.S. corporation. The efficiency of the Kalina Cycle® is 40% to 70% higher than Rankine steam cycles for low and intermediate temperature heat sources. The process uses a binary working fluid of ammonia and water with proprietary and patented processes for varying the ammonia concentration throughout the system and for heat recuperative stages for increased efficiency. The use of ammonia permits efficient use of waste heat streams allowing boiling to start at lower temperatures. The use of a binary fluid allows the composition of the working fluid to be varied through the use of distillation, providing a richer concentration through the boiler and leaner composition in the low-pressure condenser. Since the molecular weight of ammonia is close to that of water, a standard back-pressure turbine can be used for energy generation (EXERGY, 2001).

One of the key subsystems of the Kalina Cycle® is the Distillation/Condensation Subsystem (DCSS), which represents the principal difference between the Rankine Cycle and the Kalina Cycle® in power plant structure and enables different working fluid mixtures at different stages of the cycle. It provides the vital function of establishing the high ammonia-water concentration for the heat acquisition stage and a low ammonia-water concentration at the condensation stage.

The DCSS consists of a series of separators, heat exchangers and pumps, all of which are constructed with standard power plant components. The composition of the working fluid is changed in the separators through the process of distillation. Final condensation occurs in heat exchangers where the working fluid is cooled by external ambient cooling systems in the same process as is used in Rankine Cycle systems.

2.2 Commercialization Status

There are several commercial applications globally with relevant experiential operational data to support Kalina Cycle® development in Hawaii. The first commercial-scale application of Kalina Cycle® technology was demonstrated at the 3.2 MW Kalina Cycle® Demonstration unit built in 1992 at a U.S. Department of Energy (DOE) research facility in Canoga Park, California as a waste heat recovery power plant and subsequently converted to a 6.5 MW combined cycle power plant in 1996. It had over 7000 hours of operation and testing before the DOE closed down their research facility.

Further development of the technology ensued when a waste-to-energy power plant and a waste heat power plant in conjunction with a steel manufacturing facility in Japan were commissioned in 1999. Following the Japanese development, a Kalina Cycle® project using a geothermal heat source was commissioned in Husavik, Iceland in 2000; two other geothermal projects are currently in the design stage. A diesel bottoming cycle power plant in Alaska is also currently in the design stage.

Along with these existing and impending projects, EXERGY/Recurrent Resources, LLC is bidding several gas pipeline gas turbine bottoming cycle projects in the 50 MW range with Siemens in Europe. EXERGY/Recurrent Resources, LLC also possesses a memorandum of understanding (MOU) for two waste heat projects for cement facilities in India, and has proposals under review and pre-proposal analysis in progress for several other projects globally (EXERGY, 2001).

3.0 WASTE HEAT RESOURCES IN HAWAII

As discussed previously in Section 2.0, Hawaii possesses a relatively diverse energy portfolio which creates various potential waste heat resources with potential for further exploitation to maximize energy recovery via the Kalina Cycle®. The following table presents the ten largest power plants in the state of Hawaii by generating capacity.

Each of these power plants, and others not presented in the previous table, create waste heat energy which is lost to the environment in the form of increased temperature of cooling waters, radiant losses to the ambient atmosphere or through flue or stack heated gas emissions. This waste heat can be significant in even the most efficiently designed conventional power plant facilities. A quick analysis of the estimated waste heat available in Hawaii attributable to the power produced from conventional fossil fuel based facilities follows.

Table 3.1: Ten Largest Plants by Generating Capacity, 1999

(Courtesy of Energy Information Administration, State of Hawaii)

Plant	Primary Energy Source(s)	Operating Company	Net Summer Capability (MW)
1. Kahe	Petroleum (Oahu)	Hawaiian Electric Co. Inc.	582
2. Waiau	Petroleum (Oahu)	Hawaiian Electric Co. Inc.	457
3. Kalaeloa Cogeneration	Petroleum (Oahu)	Kalaeloa Partners LP	261
4. AES Hawaii Inc.	Coal (Oahu)	AES Hawaii Inc.	189
5. Maalaea	Petroleum (Maui)	Maui Electric Co. Ltd	168
6. Honolulu	Petroleum (Oahu)	Hawaiian Electric Co. Inc.	100
7. Port Allen	Petroleum (Kauai)	Citizens Utility Co.	97
8. H-Power	Waste (Oahu)	DFO Partnership	61
9. Hamakua Energy Plant	Coal/Biomass (Maui)	Hawaiian Coml & Sugar	58
10. WH Hill	Petroleum (Hawaii)	Hawaii Electric & Light Co.	35

Hawaiian Electric Company (HECO) suggests a heat rate of ~ 596 kWh/bbl of low sulfur residual fuel oil rated at approximately 6,287,000 Btu/bbl which yields 10,549 Btu/kWh. With a suggested conversion rate to electricity of approximately 32.35%, there is approximately 7,137 Btu/kWh of waste heat. Most of this is emitted via the cooling water while a small portion (~2% of the input) is radiant energy and the rest goes up the stack.

Utilizing the following assumptions:

Average stack gas temperature = 350°F (see Table 4.2)
Inlet air and cooling water temperature = 80°F (see Table 4.2)
25% excess air (DBEDT, 2003)
Heat rates discussed above

Heat Balance:

Cooling water	53.44%	5,637 Btu/kWh generated
Electricity	32.35%	3,412 Btu/kWh generated
Stack gas	12.21%	1,288 Btu/kWh generated
Radiation losses	2.00%	211 Btu/kWh generated
TOTAL	100.00%	10,549 Btu/kWh generated

The total amount of electricity generated in Hawaii is approximated by 10,000,000,000 kWh/yr (Hawaii Data Book, 2001). Therefore, the total waste heat for fossil fuel based power plants is approximated as follows:

12,880,000,000,000 Btu/yr (stack gases at 350°F) with air and cooling water temperatures of 80°F if this is converted at 50% of the Carnot efficiency (or 16.7%) this yields a waste heat value of approximately 631 million kWh/yr from stack gas losses.

56,364,000,000,000 Btu/yr (cooling waters leaving at 90°F) (see Table 4.2)

if this is converted at 50% of the available Carnot efficiency (or 0.8%) this yields a waste heat value of approximately 132 million kWh/yr from cooling water losses.

TOTAL = 763 million kWh/yr or approximately 7.6% of current production

Conventional power is not the only resource for waste heat application in Hawaii. Hawaii's unique geology and remote location in the tropical ocean have provided relatively rare waste heat potential which needs to be investigated as well. Specifically, Hawaii's geographic location within the tropical region of the Pacific Ocean makes it a viable candidate to exploit the largest solar collector on the planet, and subsequently the largest potential natural, renewable energy resource available, the heat stored in the tropical ocean. The resource available to Hawaii is virtually unlimited as the thermal resource from whence it derives its heat content is the tropical sun incident upon and absorbed by the warm tropical surface water. This thermal heat source is three dimensional in nature as the top 150 – 300 feet (50 – 100 meters) of the tropical ocean is an isothermal mixed layer which effectively stores the solar radiation incident upon it each day. The accessible renewable energy potential within the immediate control of the State of Hawaii is many orders of magnitude higher than the current energy consumption required by the *entire* state.

Another potential waste heat source available due to Hawaii's unique geology is from the Puna Geothermal facility in Puna, Hawaii. Currently, the Puna facility only utilizes the pressurized steam which is emitted from its resource well and pumps the pressurized brine directly to be reinjected with the condensed steam after utilization in the power production process. This geothermal brine represents a substantial waste heat resource amenable to exploitation via Kalina Cycle® technology. A quick analysis of the magnitude of this resource is provided.

Utilizing the following assumptions:

Average brine temperature = 300°F (149°C) (Puna Geothermal Venture, 2003)
Average brine flow = 1.5 million lb/hr (189 kg/s) (Puna Geothermal Venture, 2003)

Inlet air temperature = 80°F (27°C – no cooling water available)

2,903,000,000,000 Btu/yr (available waste heat)

If converted at 50% Carnot efficiency (or 14.5%) this yields approximately 123 million kWh/yr of usable waste heat lost in the brine. With a total current plant capacity of 35 MW (or 307 million kWh/yr electricity generation), this waste heat, presently reinjected with the brine, could theoretically generate an additional 40% more electricity than is currently produced!

With just a few quick calculations it becomes evident that the waste heat potential in the State of Hawaii available for recovery through implementation of the Kalina Cycle® is substantial.

4.0 KALINA CYCLE® APPLICATIONS

The potential applications of Kalina Cycle® technology are evaluated and prioritized in the following section according to potential and relevant applicability to Hawaii's needs and resource availability.

4.1 Ocean Thermal Energy Conversion (OTEC)

By far the largest "waste heat" resource available in Hawaii for Kalina Cycle® application is the heat stored in the tropical ocean surrounding the state. The means by which the Kalina Cycle® can harvest this energy is by using the technology referred to as Ocean Thermal Energy Conversion, or OTEC. Essentially, there are two scenarios proposed for application of this technology for the State of Hawaii. The two scenarios are summarized below.

4.1.1 Integrated, Multi-Product Land Based OTEC Systems

The first application anticipated for Kalina Cycle® OTEC is as the power cycle for delivering net power in an integrated, multi-product land-based OTEC system for one or more islands in the Hawaiian chain. Hawaii, Lanai, Kaho'olawe, Maui, Oahu and Kauai all possess amenable access to the necessary resources for supporting a land-based OTEC facility. Although the installed cost per kW of an OTEC system is still not competitive for land-based systems on purely a power generation scenario, consideration of a multi-product system providing several revenue generating products utilizing the same resource flows can be shown to provide the necessary profit potential to attract investors to this type of power system. Potential co-products to OTEC power generation are shown below in Figure 4.1.

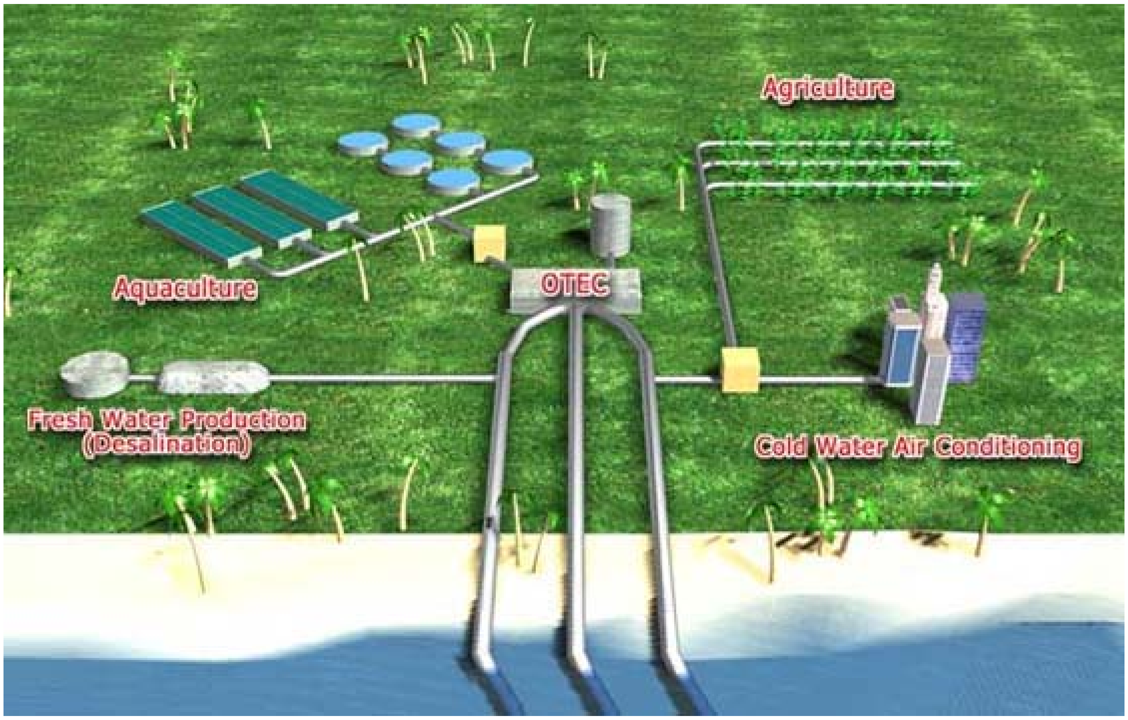


Figure 4.1: Schematic of Integrated Multi-Product OTEC System

Potential applications of this technology have been proposed for several locations within the state. Specifically, a 1.2 MW Kalina Cycle® facility was proposed to provide power to the Natural Energy Laboratory of Hawaii Authority (NELHA) on the big island of Hawaii in 2000. An integrated facility producing fresh water to reforest Kaho'olawe and provide revenue to the island through the sale of net electricity to Lanai and Molokai has been discussed. Finally, a Kalina Cycle® OTEC system to provide the necessary energy to operate a desalination plant on the island of Oahu has been commissioned by the Honolulu Board of Water Supply and is currently being investigated.

This option was chosen as the most immediately promising application of the Kalina Cycle® waste heat recovery with the most potential for application in Hawaii. Therefore, a more detailed discussion and a preliminary design have been prepared for such a system in Section 6 of this report.

4.1.2 Large Off-Shore OTEC Systems

Ultimately, the greatest potential for addressing the growing energy needs in the State of Hawaii and fulfilling the requirements by the federal and state governments to replace a significant portion of the State's energy production with renewable energy resources will necessitate the integration of the Kalina Cycle®

into floating platform OTEC technology. Current oil exploration technology has developed drilling platforms which operate in depths in excess of 1000 meters. This technology makes the development of floating 100 MW OTEC systems just offshore of nearly any of the islands within the Hawaiian archipelago a technologically manageable project, today. Incorporating this platform technology into OTEC technology allows for much larger systems than can be economically and technologically built on land, with significantly better overall economics for energy production. With the energy generated on an off-shore facility and transported via a submerged cable system to the demand centers on a nearby island(s), the economics of scale begin to bring OTEC energy into the competitive realm of more traditional systems (see the economic analysis presented in Section 5).

4.2 Geothermal

One of the most promising immediate applications in Hawaii for the Kalina Cycle® process is to waste heat recovery from geothermal power facilities. The Kalina Cycle® is an ideal process for recovering waste heat available in geothermal brine which is often ignored in most geothermal power production facilities. The Kalina Cycle® is touted to increase plant efficiencies from 30 – 50% over more traditional Rankine Cycle applications and reduce plant construction costs by 20 - 30%, thereby dramatically lowering the cost of geothermal power generation (EXERGY, 2001).

4.2.1 Existing Kalina Geothermal Facilities

The Orkuveita Husavikur power plant is the first geothermal application of the Kalina Cycle®. The Orkuveita Husavikur Geothermal Power Plant in Husavik, Iceland, was developed and built in 1998-2000 to establish a municipal electrical power plant, using hot fluid piped from the Hveravellir geothermal field south of the town. The resulting installation is a vivid demonstration of the practical value of a Kalina Cycle® plant in cost-effectively generating electrical power from a low-temperature geothermal source. The Orkuveita Husavikur Geothermal Power Plant entered service in July, 2000. After 18 months of operation, the plant has realized Orkuveita Husavikur's technical and commercial objectives – greater than 1,600 kW of cost-effective, clean base load power at an exceptional level of efficiency, reliability and availability (Mirolli et al, 2002).

While the Kalina Cycle® may seem complex, operation is quite simple. The Husavik Kalina plant operates unattended for the majority of the time. Except for the turbine (which every geothermal power plant has), the process is no more complex than that found within an ammonia absorption refrigeration plant. The different ammonia concentrations in various parts of the process are not controlled. They are naturally set by the system pressures and temperatures of the process – they seek their own balance. Besides the turbine controls, there are only four control loops: 1) the feed flow control valve, which is controlled in proportion to the geothermal brine flow, 2) the separator level control, 3) the drain tank level control, and 4) the turbine by-pass valve which only operates at plant start-up and shut-down. This level of automation allows for very small operational and maintenance costs to be associated with Kalina Cycle® technology thereby further enhancing its economic attractiveness to low temperature waste heat applications.

In September, 2002, Advanced Thermal Systems, Inc., an energy technology and development company, announced the signing of an engineering, procurement and construction (EPC) contract with GE Oil & Gas, for a new 40 MW Steamboat IV Kalina Cycle® geothermal power plant to be located at its Steamboat geothermal power park, nine miles south of Reno, Nevada. The Steamboat IV plant is expected to be operational in early 2005. The Steamboat IV plant will be an air-cooled geothermal system which will employ Recurrent Resources patented Kalina Cycle® technology and will operate very similarly to what could be applied at the Puna Ventures Geothermal Power Plant as described in Section 4.2.2.

4.2.2 Puna Geothermal Venture

The Big Island of Hawaii possesses the geological environment to provide the necessary natural geothermal activity from which a significant portion of its energy base could theoretically be derived. Currently, only 35 MW (~20% of Hawaii's energy needs) are generated at only one geothermal power facility located in Puna, Hawaii. Plans to expand the facility to 65 MW are currently being considered. Coordinating with the expansion process for implementing a Kalina Cycle® waste heat recovery facility to capture the waste heat from the geothermally heated brine currently lost and reinjected into the injection well could prove extremely beneficial to the Puna Venture facility through cost-effective, environmentally friendly energy production and utilization of existing resources. A schematic of the current Puna geothermal facility is shown in Figure 4.2.

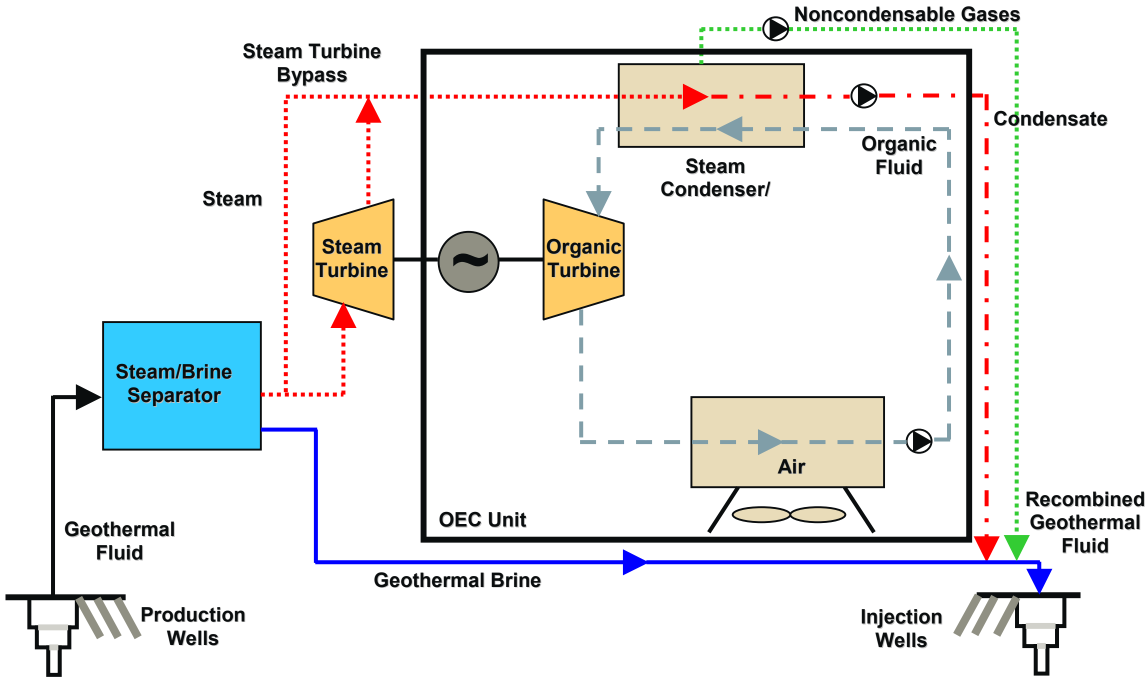


Figure 4.2: Schematic of the Puna Venture Geothermal Facility

Under the present scenario the heat in the brine accompanying the steam generated from the production well bypasses the energy production system and is reinjected with the condensed steam into the injection well (see Figure 4.2). Implementation of Kalina Cycle® technology would simply involve connecting a Kalina Cycle® power production facility to the existing brine stream (see Figure 4.3) which would function as the heat source for the Kalina process and either air or seawater cooling could be employed as the necessary heat sink (analysis of the generating potential of this process is beyond the scope of this investigation and would require further evaluation as to which method would prove the most cost-effective heat sink. Ground water resources available at the Puna facility are too warm and limited to provide the necessary heat sink for efficient power production). A Kalina plant design allows the geothermal fluid to remain condensed at high pressure throughout the process, so that it can be easily recycled down the injection well. The Kalina Cycle® also has the potential to allow continued electricity generation to even lower temperatures in future developments and as the temperature falls off as the geothermal resource is depleted.

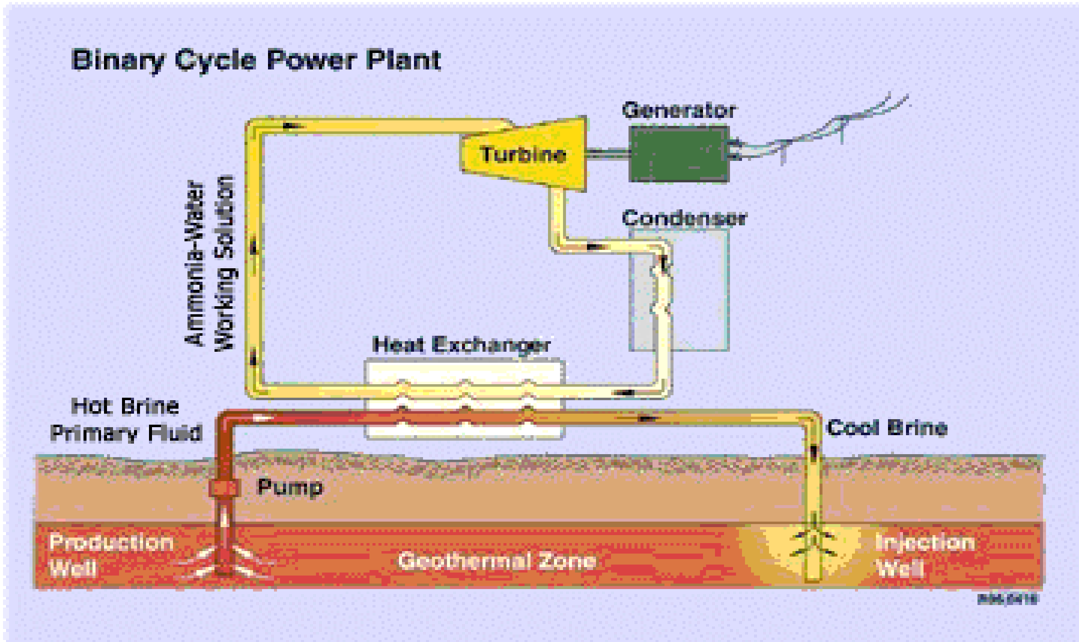


Figure 4.3: Simple Schematic of Geothermal Kalina Cycle® Application
(Courtesy: Advanced Thermal Systems, Inc.)

A comparison of the available resources at the Puna Venture facility with those utilized at the Husavik, Iceland facility are presented in Table 4.1 to show the potential benefits which can be derived by implementation of the Kalina Cycle® to the Puna Geothermal Power facility.

Table 4.1: Husavik vs. Puna Resource Comparison
(Husavik information courtesy of Recurrent Resources, LLC; Puna information courtesy of Puna Ventures, Inc.)

	Husavik, Iceland	Puna, Hawaii
Brine Flow (l/s)	**90**	**189**
Brine Temperature	**121°C**	**149°C**
CW flow (l/s)	**180**	**85 (available)**
CW Temperature	**4°C**	**40.6°C**
Power generated	**1.7 MW**	**5 – 10 MW (estimate)**
$/kW	**$ 905**	**$2,000 - $2500 (estimate)**
Total cost	**$1,875,000**	**$10,000,000 - $25,000,000**

Installed costs and $/kW for the Puna Venture Kalina Cycle® power system are expected to be very similar to those experience in the Husavik, Iceland project. As is evident by the preceding table, the resources currently available at the Puna Geothermal facility are very amenable to Kalina Cycle® development if air cooling or seawater cooling can be implemented for the heat sink (the anticipated air cooling equipment is more costly than wet cooling as utilized in Husavik, hence the higher $/kW installed capacity are anticipated and reflected in the table above). Further analysis of this potential is certainly warranted, especially in light of the planned expansion of the geothermal facility.

4.3 Waste Heat Recovery

Waste heat recovery from existing facilities in Hawaii is applicable to four separate commercially attractive sources: 1) Petroleum based power plants – the primary source of power in Hawaii, 2) Coal fired power plants, 3) Biomass/Waste powered plants, 4) Thermally intensive industrial facilities, all of which would incorporate very similar Kalina Cycle® system configurations to recover the waste heat generally lost to the environment in the form of cooling water discharges or ambient losses to the atmosphere. The following sections discuss the potential of each waste heat resource.

4.3.1 Diesel/Oil-Fired Plants

The incorporation of a Kalina bottoming cycle for diesel/oil fired generation units can improve the station heat rate by 10 – 15% (EXERGY, 2001). This application is economically viable for most medium to large diesel generating stations (>20 MW), and is viable for small distributed power generating stations (5-20 MW) where fuel cost is high and the plant load factor is moderate to high.

The efficiency of the Kalina Cycle® is 40 -70% higher than Rankine steam cycles for low and intermediate temperature heat sources such as exhaust gas from diesel/oil generators (EXERGY, 2001). Kalina Cycle® technology is used to increase the efficiency of power plants by increasing the average temperature of heat acquisition by the working fluid and reducing the amount of heat rejected to the environment in the stack gas or cooling waters. These goals are achieved by using the binary ammonia/water working fluid as previously described in Section 1.1. The properties of the ammonia/water mixture makes a better match to the enthalpy-temperature curve of sensible heat source such as hot gas or hot water. Thus the Kalina Cycle® shows higher gross output power for relatively low temperature (100 – 200°C) heat sources over that of conventional steam turbine systems (refer to Table 4.2 below for relevant power plant waste heat data).

For a DCC project, the heat sources are the diesel exhaust gas and the engine cooling system. A Heat Recovery Vapor Generator (HRVG) is provided for each diesel (or alternatively, one HRVG for two diesel units). A rich mixture of water and ammonia is boiled and superheated in the HRVGs and the superheated vapor is expanded through a back-pressure turbine. The turbine exhaust is too rich to fully condense, so it is then cooled with a recuperative heat exchanger and diluted with the bottoms from a vapor separator/demister, and is then fully condensed. At this stage, part of the working fluid is sent to the vapor separator/demister through recuperative heat exchangers and part of the working fluid is mixed with the high ammonia concentration vapor stream from the vapor separator/demister. This process restores the working fluid to the optimum ammonia-water concentration for the heat acquisition stage of the cycle. The working fluid is then condensed and returned to the HRVGs, passing through a heat exchanger using jacket water heat and a recuperative heat exchanger that also serves as an economizer. Figure 4.4 below depicts a typical system flow for a diesel/oil Kalina bottoming cycle application.

The peak design capacity for a diesel/petroleum combined cycle (DCC) bottoming cycle depends on the following variables:

- Diesel exhaust gas temperature and flow
- Fuel sulfur content (limits the minimum stack temperature)
- Type of cooling available (water or air cooled condensers)
- Capacity of diesel generating station
- Site ambient conditions
- Diesel back pressure requirements
- Bottoming cycle design

In the case of Hawaii, most conventional power plants, which represent the majority of Hawaii's power production capacity, meet or exceed the requirements desired for implementation of the Kalina Cycle® application presented above. Specifically, Hawaii possesses several (see Table 3.1) power facilities with sufficient generating capacity, desirable exhaust gas temperatures and flows (see Table 4.2). The fuel of choice in Hawaii is generally a low-sulfur fuel, and most of the power stations utilize ambient ocean water for cooling which has excellent heat sink characteristics for utilization in Kalina Cycle® applications. The final criteria, of most importance to the HECO representatives who would be integral in the development of a Kalina Cycle® program in Hawaii, is the bottoming cycle design.

Table 4.2: HECO Power Plant Waste Heat Data

(Courtesy: Hawaiian Electric Company, 2003)

					Flue Gas		Circulating Water			Cooling Water		
								Average Temperature, F				
OPERATING COMPANY	PLANT	UNIT	Duty Cycle	Capacity Factor. %	TEMP (F)	Mass Flow, lb/hr	MGD	Inlet	Outlet	Availability	Type	Average Temperature F
HECO	Honolulu	8	Cycling	25	325	559,422	92	80	90	pump req'd	Seawater	80
HECO	Honolulu	9	Cycling	25	325	559,422	92	80	90	pump req'd	Seawater	80
HECO	Kahe	1	Base	80	424	734,205	104	See temperature record files		pump req'd	Seawater	80
HECO	Kahe	2	Base	80	404	718,370	104	See temperature record files		pump req'd	Seawater	80
HECO	Kahe	3	Base	80	423	758,004	107	See temperature record files		pump req'd	Seawater	80
HECO	Kahe	4	Base	80	413	750,911	107	See temperature record files		pump req'd	Seawater	80
HECO	Kahe	5	Base	80	430	1,175,580	212	See temperature record files		pump req'd	Seawater	80
HECO	Kahe	6	Base	80	418	1,094,135	212	See temperature record files		pump req'd	Seawater	80
HECO	Waiau	3	Cycling	25	385	535,608	68	80	90	pump req'd	Seawater	80
HECO	Waiau	4	Cycling	25	385	535,608	65	80	90	pump req'd	Seawater	80
HECO	Waiau	5	Cycling	25	286	488,946	80	80	90	pump req'd	Seawater	80
HECO	Waiau	6	Cycling	25	286	488,946	80	80	90	pump req'd	Seawater	80
HECO	Waiau	7	Base	80	300	860,940	107	80	90	pump req'd	Seawater	80
HECO	Waiau	8	Base	80	313	845,308	107	80	90	pump req'd	Seawater	80
HECO	Waiau	9	Peaking	5	1090	1,771,336	none			none		
HECO	Waiau	10	Peaking	5	1090	1,771,336	none			none		
MECO	Kahului	K-1	Base	80	350	77,411	55	80	90	pump req'd	Seawater	80
MECO	Kahului	K-2	Base	80	300	81,817	Included in K-1			pump req'd	Seawater	80
MECO	Kahului	K-3	Base	80	325	138,522	Included in K-1			pump req'd	Seawater	80
MECO	Kahului	K-4	Base	80	320	184,981	Included in K-1			pump req'd	Seawater	80
MECO	Maalaea	M1	Cycling	25	760	49,221	none			none		
MECO	Maalaea	M2	Cycling	25	760	49,221	none			none		
MECO	Maalaea	M3	Cycling	25	760	48,435	none			none		
MECO	Maalaea	M4	Cycling	25	822	89,671	none			none		
MECO	Maalaea	M5	Cycling	25	822	89,671	none			none		
MECO	Maalaea	M6	Cycling	25	822	89,671	none			none		
MECO	Maalaea	M7	Cycling	25	822	89,671	none			none		
MECO	Maalaea	M8	Cycling	25	840	107,295	none			none		
MECO	Maalaea	M9	Cycling	25	840	107,295	none			none		
MECO	Maalaea	M10	Cycling	25	700	229,687	none			none		
MECO	Maalaea	M11	Cycling	25	700	229,687	none			none		
MECO	Maalaea	M12	Base	80	700	229,687	none			none		
MECO	Maalaea	M13	Base	80	700	229,687	none			none		
MECO	Maalaea	X1	Peaking	5	760	47,690	none			none		
MECO	Maalaea	X2	Peaking	5	760	47,690	none			none		
MECO	Maalaea	M14 Comb.	Base	80	309	613,793	none			none		
MECO	Maalaea	M16 Comb.	Base	80	309	613,793	none			none		
MECO	Maalaea	M17 Simple	Peaking	5	1018	614,520	none			none		
MECO	Maalaea	M19 Simple	Peaking	5	1018	614,520	none			none		
MECO	Miki Basin	1	Cycling	25	640	21,644	none			none		
MECO	Miki Basin	2	Cycling	25	640	21,644	none			none		
MECO	Miki Basin	3	Cycling	25	640	21,644	none			none		
MECO	Miki Basin	4	Cycling	25	640	21,644	none			none		
MECO	Miki Basin	5	Cycling	25	640	21,644	none			none		
MECO	Miki Basin	6	Cycling	25	640	21,644	none			none		
MECO	Miki Basin	7	Base	80	776	33,933	none			none		
MECO	Miki Basin	8	Base	80	776	33,933	none			none		
MECO	Palaau	3	Peaking	5	713	13,933	none			none		
MECO	Palaau	4	Peaking	5	713	13,933	none			none		
MECO	Palaau	5	Peaking	5	713	13,933	none			none		
MECO	Palaau	6	Peaking	5	713	13,933	none			none		
MECO	Palaau	7	Base	80	776	33,933	none			none		
MECO	Palaau	8	Base	80	776	33,933	none			none		
MECO	Palaau	9	Base	80	776	33,933	none			none		
MECO	Palaau	CAT-1	Peaking	5	968	13,040	none			none		
MECO	Palaau	CAT-2	Peaking	5	968	13,040	none			none		
MECO	Palaau	CT-1	Peaking	5	720	139,285	none			none		
HELCO	Hill	CT-1	Peaking	5	835	156,964	none			none		
HELCO	Hill	5	Base	80	422	152,268	23	68	89	See note 1	well	68
HELCO	Hill	6	Base	80	274	329,143	36	68	89	See note 1	well	68
HELCO	Hill	11	Cycling	25	739	40,943	none			none		
HELCO	Hill	15	Cycling	25	761	49,602	none			none		
HELCO	Hill	16	Cycling	25	761	49,602	none			none		
HELCO	Hill	17	Cycling	25	761	49,602	none			none		
HELCO	Keahole	D18	Cycling	25	759	48,184	none			none		
HELCO	Keahole	D19	Cycling	25	759	48,184	none			none		
HELCO	Keahole	D20	Cycling	25	759	48,184	none			none		
HELCO	Keahole	D21	Cycling	25	759	48,184	none			none		
HELCO	Keahole	D22	Cycling	25	759	48,184	none			none		
HELCO	Keahole	D23	Cycling	25	759	48,184	none			none		
HELCO	Keahole	CT-2	Cycling	25	705	778,810	none			none		
HELCO	Puna	CT-3	Cycling	25	1018	611,940	none			none		
HELCO	Puna	Boiler	Base	80	300	527,163	12	68	90	See note 1	well	68
HELCO	Shipman	S-3	Cycling	25	352	272,177	28	68	84	See note 1	well	68
HELCO	Shipman	S-4	Cycling	25	352	272,177	Included in Shipman S-3			See note 1	well	68
HELCO	Waimea	12	Cycling	25	760	49,755	none			none		
HELCO	Waimea	13	Cycling	25	760	49,755	none			none		
HELCO	Waimea	14	Cycling	25	760	49,755	none			none		
Capacity Factor: % of time unit is operating on the average per year										Note 1: All circulating water used for plant, no extra available.		

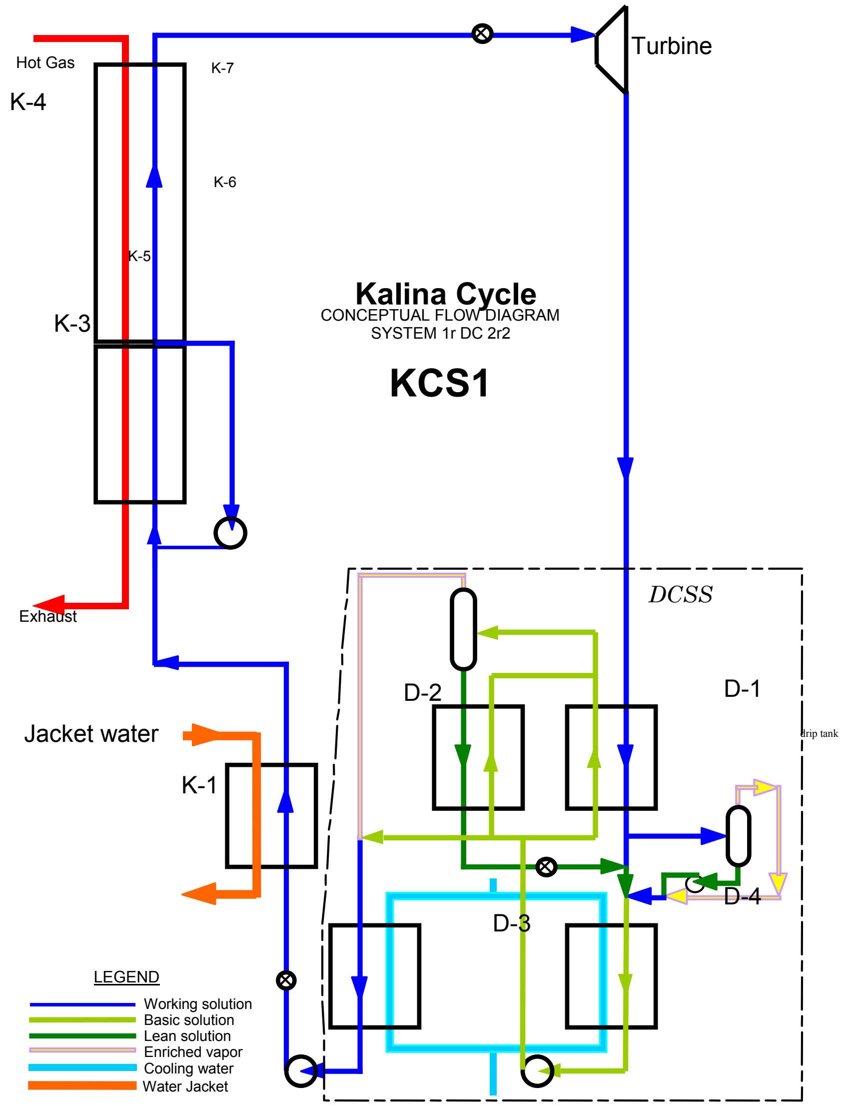


Figure 4.4: Conceptual Flow Diagram for a Kalina Diesel Combined Cycle (DCC) System

Hawaii's existing petroleum-based power facilities are necessarily designed for optimum utilization of existing space. Therefore, retrofitting an existing facility would be extremely rigorous and economically undesirable due to very limited extraneous floor space available. Fortunately, the Kalina Cycle® is a system that can be designed *vertically* instead of horizontally to accommodate such space restrictions and should be able to satisfactorily address these concerns and warrants further investigation in conjunction with HECO engineers.

4.3.2 Coal Fired Plants

There are currently two existing coal fired plants operating in Hawaii with another plant in consideration for the next expansion planned by HECO. The primary existing plant is owned by AES Hawaii and generates approximately 190 MW (see Table 3.1) on the island of Oahu. The second coal facility is located on Maui and operates in conjunction with biomass as its working fuel (Hawaiian Commercial & Sugar Co.) and has a generating capacity of approximately 60 MW. These two facilities operate as typical steam generation facilities similar to the diesel/petroleum plants described above. Implementation of the Kalina Cycle® bottoming cycle into these facilities should prove economical as their generating capacity is sufficient to suggest significant waste heat resources are available in their stack gas if access to amenable heat sink sources is available. Further analysis of these facilities is warranted to determine the level of contribution integration of a Kalina Cycle® bottoming cycle facility could add to the existing coal fired power system.

4.3.3 Biomass/Waste Plants

With the demise of the sugarcane and pineapple industries, biomass power systems in Hawaii are virtually non-existent save the lone facility on Maui (see Table 3.1) which also operates with coal to maintain generating capacity when biomass fuel is insufficient for optimum operation. A Kalina bottoming cycle configuration similar to the one described for the petroleum based plants would be feasible at this facility given the anticipated stack temperatures and system flows which are obviously present due to the capacity of the power facility. Further analysis is warranted to determine the detailed benefit and system size for such a design.

Similarly, there is only one significant waste-to-energy facility operating in Hawaii and that is H-Power on the island of Oahu. H-Power produces approximately 7% of Oahu's electricity and reduces the volume of refuse going to landfill by 90%. H-Power operates as a typical steam power plant with a five cell cooling tower using ambient saline water taken from Cap rock wells on site as the heat sink medium. The exhaust gas from the plant exits at a temperature of approximately 121°C (250°F). Each boiler is approximately operated at a rate of 240,000 lbs of steam an hour with no re-heat of turbine (H-Power, 2003). No further mass flows were available at the time of this writing. Similar to the analyses presented for other technologies, these temperatures and flow rates indicate that the existing system could benefit from the integration of a Kalina bottoming cycle to capture some of this waste heat currently lost to the environment. The Kalina Cycle® has been successfully applied to a commercial waste-to-energy facility similar to H-Power in Japan and began operation in 1999 (previously mentioned in Section 1.2). Further analysis of this potential is beyond the scope of this report but is warranted.

4.3.4 Industrial Facilities

Hawaii's heavy industries typically associated with large energy requirements for high temperature processes such as steel and cement manufacture are essentially non-existent due to space limitations and lack of readily available raw materials. Therefore, potential industrial applications of the Kalina Cycle® within the state of Hawaii are extremely limited. The only potential industrial application identified in this study was implementation of the Kalina Cycle® as a waste heat recovery process coupled with the Tesoro and Chevron refineries located in the Campbell Industrial Park on Oahu. However, due to the relative instability and uncertain future of those facilities here in Hawaii, they are deemed a poor choice for immediate consideration and are not considered any further.

5.0 ECONOMIC ANALYSES AND COMPARISONS

Generally speaking, the capital cost for a Kalina bottoming cycle is expected to be less than that of a Rankine bottoming cycle in terms of installed capacity ($/kW) for each of the proposed applications, but more than a diesel generation power plant of equivalent capacity (Exergy, 2001). However, the Kalina Cycle® savings in fuel more than makes up for the differential in capital cost between incremental addition of diesel/petroleum generating capacity and using a Kalina bottoming cycle. The savings in fuel cost depends on the type of fuel used. In addition, the impact on the need for standby diesel generation capacity for the frequent diesel unit maintenance needs to be considered in any future economic assessment. A brief economic assessment for each proposed Kalina Cycle® application is presented.

5.1 OTEC Economics

As previously mentioned, shore-based OTEC systems are still not economically competitive with conventional power production based upon a power only assessment. However, OTEC's unique characteristics provide natural synergies which allow for additional co-product's which greatly enhances the revenue which can be realized from an integrated multi-product OTEC system. Specifically, under amenable conditions, an integrated OTEC system can produce several high value products such as fresh water, seawater air conditioning, ice, aquacultural and agricultural products; all of which can enhance the economic viability of the power system. When a complete system economic analysis is performed, especially in areas of high power and water costs (e.g., Lanai), integrated Kalina Cycle® OTEC systems can be shown to be cost competitive with existing conventional systems.

In regards to a floating OTEC plant, a preliminary internal economic analysis performed by the reporting company, OCEES International, Inc., indicates that for a 100 MW floating facility as described in section 4.1.2 with a total plant cost approaching $400 million, a 6% interest rate on capital and an anticipated 20 year life-cycle; the low operation and maintenance (O&M) costs for a plant of this nature would produce energy at a break-even cost of approximately 4¢/kWh – a very competitive price for electricity production in Hawaii. This means of harnessing the vast resource stored in the tropical ocean via the Kalina Cycle® is the most economically viable application of OTEC technology for Hawaii and possesses the greatest potential of any renewable to dramatically contribute to the net generating capacity to meet government mandates for emission reduction.

5.2 Geothermal Economics

Funded in 2000 by an R&D grant from the U.S. Department of Energy (DOE), a conceptual design was performed to determine the feasibility of applying the Kalina Cycle® to recover energy from a 171°C geothermal brine being injected from an existing geothermal power plant (Harry Blundell Geothermal Power Plant) tapping Roosevelt Hot Springs in Utah. The study evaluated the feasibility of applying a Kalina Cycle® system to recover additional energy from the hot fluid reject stream currently being injected with condensed steam back into the injection well (just as is experienced in Puna). Also, the analysis included a design using a dry cooling (air cooled) tower to avoid competition with other water uses at the facility – just as would be necessary at the Puna Geothermal Power Plant on Hawaii. Due to the inherent similarities between the Blundell facility and the Puna facility, the following financial performance of the Blundell study should closely model the economic performance which can be attained at the Puna site through similar application of the Kalina Cycle® to heat recovery at that facility.

Anticipated Financial Performance (Lewis and Ralph, 2001):

POWER Engineers, Inc. performed the feasibility analysis on the Blundell plant utilizing GT Pro software to model the technical and economic performance of the Kalina plant presented in Table 5.1 below. The model showed a break-even electricity price for the Kalina plant of 3.14 ¢ per kWh. (Incidentally, a model run showed a break-even electricity price of 4.29 ¢ per kWh for a gas-fired 7FA combustion turbine at the same site, assuming a gas price of $5/mm Btu. Though the gas turbine plant can boast of initially lower cost per MW, the advantages of no fuel costs allow the bottoming plant to take a decisive advantage over the project life span in terms of cost per kWh (Lewis and Ralph, 2001)). The Kalina economic evaluation did not take into account any increased market value for green power or possible implementation of production tax credits which may be applicable here at the Puna site.

Table 5.1: Life Cycle Plant Performance Comparison Analysis of a Kalina Plant at the Blundell Site

	Blundell Kalina Bottoming Cycle
Annual Electricity Exported (10^6 kWh)	105
Total Investment	$28,073,000
Specific Investment	$2,2245.50 per kW
Initial Equity	$8,422,000
Cumulative Net Cash Flow	$81,312,600
Internal Rate of Return on Investment (ROI)	16.15%
Years for Payback Equity	3.76 years
Net Present Value	$10,295,000
Break-even Electricity Price	3.14¢ per kWh

Assumptions for Blundell model development:

- First year of operation is 2003
- Annual operating hours of 8,410 for the Kalina plant
- Project life of 20 years
- Straight-line depreciation life of 15 years
- Debt term of 15 years
- Depreciable percent of total investment, 90%
- Debt percent of total investment, 70%
- Debt interest rate, 9%
- Overall tax rate, 35%
- First-year electricity price 0.05 $/kWh
- Discount rate for NPV calculation, 15%
- Escalation rate, 4.5%

After analyzing this economic evaluation and comparing it to what could be obtained here in Hawaii for the Puna Geothermal facility, it is quite evident that a more detailed analysis of the Puna facility is warranted and that application of the Kalina Cycle system is likely a good decision for integration in their current system as well as for future expansion plans.

5.3 Diesel/Petroleum Bottoming Cycle Economics

It has already been discussed that the implementation of the Kalina Cycle® in bottoming cycle applications for the large diesel/petroleum based power systems, which dominate the Hawaii power landscape, is a more economical approach than a more traditional Rankine cycle. Likewise, an economic analysis would show that addition of a Kalina bottoming cycle is a better choice above incremental increases in diesel or other fossil fuel power production systems through an appropriate life-cycle cost analysis in spite of its relatively larger initial capital cost. The Kalina Cycle's lack of fuel costs and need for redundant capacity generally associated with conventional power production facilities further supports this conclusion. As previously mentioned, a more dire concern to the HECO engineers is the space required to retrofit the existing facilities to accommodate such a bottoming cycle. This along with a complete economic analysis is beyond the scope of this report. However, the waste heat evaluated in Section 3 and displayed in Table 4.2 show that the potential for this application is significant here in Hawaii and warrants further serious consideration.

Economic Viability of Small Kalina Diesel Generator Combined Cycle Projects

Depending on the diesel unit efficiency and the waste heat exhausted from the diesel engine, the anticipated capacity of a Kalina Bottoming Cycle is 10% to 15% of the diesel unit capacity for small stations. The following discussion establishes general guidelines for quickly identifying the most viable projects and determining the appropriate priorities for subsequent engineering and economic evaluation.

The economic viability of adding a Kalina Bottoming Cycle to an existing diesel generation station depends on the following:

- Size of the Diesel Station
- Number and Capacity of Each Diesel Unit
- Diesel Unit Annual Average Capacity Factor
- Diesel Unit Exhaust Heat Rejection
- Capital Cost of the Kalina Bottoming Cycle Power Plant
- Avoided Cost of Energy (Purchased Energy Tariff or cost of fuel and O&M)
- Kalina Cycle® Power Plant O&M Cost
- Escalation Assumptions
- Discount Rate or Cost of Capital
- Debt Assumptions
- Tax Assumptions

Significant engineering and economic analysis is required to develop the input for a rigorous evaluation. However, some general assumptions have been made for purposes of preliminary analysis and have been used to develop of a set of curves to be used for preliminary screening of possible projects.

Exergy (2001) has done this analysis and developed the preliminary screening criteria summarized in Figure 5.1. This chart shows the combined effect of diesel station size, average load factor and ACE (avoided cost of energy) on the viability of incorporating a Kalina Bottoming Cycle. Any diesel station that is "above the curve" is economically viable for a bottoming cycle. The analysis is for diesel stations that have a combined capacity of 2.0 MW to 12.0 MW (of diesels available for adding a bottoming cycle), and have an ACE ranging from $0.10/kWhr to $0.20/kWh. The ACE is either purchased electricity tariff or the fuel and O&M cost (per kWhr) of existing capacity. [Note: Only those diesel units that are to be used for the heat source should be included when considering the combined diesel capacity for purposes of calculating potential Kalina Cycle® capacity]. The most obvious possible applications of the Kalina Cycle bottoming cycle within these limitations are located on Lanai and Molokai where the ACE might fall within the required range. Further investigation of these power facilities is required to determine economic viability.

An example of how these curves can be used follows. Assume there is a remote community that has a marginal cost of energy production (ACE) of $0.14/kWh with a diesel station that has four 2000 kW diesel units that are operated as indicated below:

1x2000 kW	Base loaded (average capacity factor of 85%)
1x2000 kW	Load following, becomes base loaded when other unit is down (average capacity factor of 40%)
1x2000 kW	Peaking (average capacity factor of 20%)
1x2000 kW	Standby (average capacity factor of 5%)

The base loaded unit and the load following unit have a combined capacity of 4000 kW. If we look at Figure 5.1, a 4000 kW diesel generation station heat source with an Avoided Cost of Energy of $0.14/kWhr would require an Annual Average Capacity Factor of at least 46% to warrant further analysis. The average capacity factor of the two units is 62.5%. Therefore, this station passes the preliminary screening test and should be analyzed further for building a Kalina Bottoming Cycle at this station. It is anticipated that the power facilities servicing Lanai and Molokai could very well fall within the limiting factors and warrant further investigation.

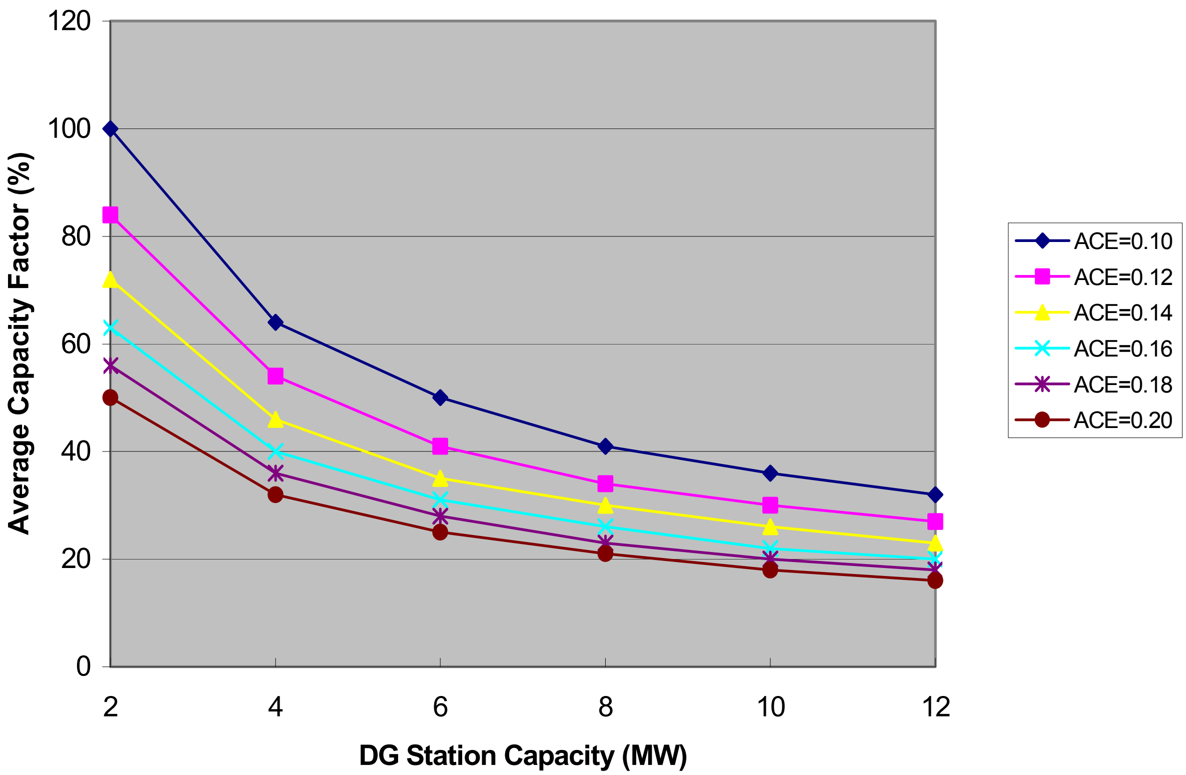


Figure 5.1: DG Combined Cycle Screening Criteria

The steps for using the Preliminary Screening Chart are summarized below:

Step 1: Determine the combined capacity of base loaded and load following diesel units for the station.

Step2: Determine the Avoided Cost of Energy (either tariff for purchased energy, or marginal cost of generation if other units are to be shut down or reduced in operation).

Step 3 Use this data to enter Figure 5.1 to determine the minimum average capacity factor to pass the screening test.

Step 4: Calculate the combined average capacity factor for the applicable diesel units.

Step 5: Compare the minimum average capacity factor with the calculated average capacity factor.

Step 6: If the calculated average capacity factor is greater than the minimum average capacity factor from Figure 5.1, the project warrants more detailed analysis.

Each of the proposed scenarios for waste heat recovery utilizing the Kalina Cycle® technology investigated in this report has proven economically attractive upon first evaluation. Further analysis is definitely warranted to verify the commercial viability of each application and its potential energy contribution within the State of Hawaii's energy portfolio.

6.0 KALINA CYCLE® OTEC PRELIMINARY DESIGN

As OTEC holds the greatest theoretical potential for contributing to power production utilizing Kalina Cycle® technology within the State of Hawaii, a preliminary design for a Kalina Cycle® OTEC power facility is presented.

6.1 Resource Availability

In order for OTEC to be a viable option for application in a tropical island community, the island must be amenably located within the tropic zone (in order to provide warm seawater in excess of 24°C year round) and have relatively immediate access to deep cold water (approximately 4°C, generally in excess of 3000 feet (1000 meters)). Most of Hawaii's islands meet these criteria.

Hawaii's access to OTEC resources is quite extensive. Nearly every populated island (excluding Molokai) in the Hawaiian chain has amenable access to the required deep ocean waters. This means that for floating OTEC plants (of 100 MW capacity) every island could potentially be serviced by such a facility either directly off shore or electricity could be cabled on shore through a submerged cable system from a nearby island's facility (i.e., servicing Lanai, Molokai and Maui from one off shore facility of this size). The most amenable bathymetries for land-based OTEC systems occur off the south and western shores of Hawaii, Kauai and Lanai; the western shores of Oahu; and a small area off the eastern shore of Maui. The location for which the following Kalina Cycle® OTEC power facility was designed is the Barbers Point to Kahe Point region depicted in Figure 6.1 below.

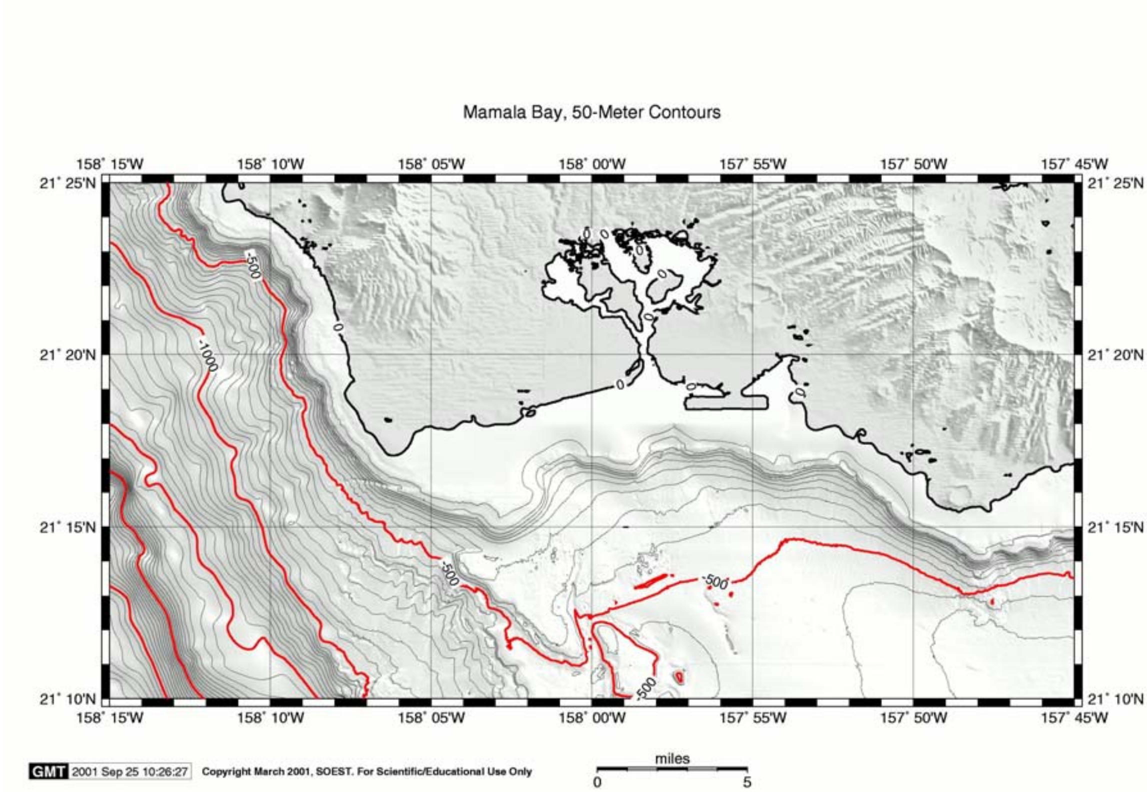


Figure 6.1: Mamala Bay Area – Amenable for Oahu OTEC Development

The surface water in this region meets the warm water requirements with an average yearly temperature of approximately 26°C (~77-78°F) as determined from data collected by HECO for the Kahe Point Power Plant cooling water intake temperatures from 2000-2002 displayed in Figure 6.2 below.

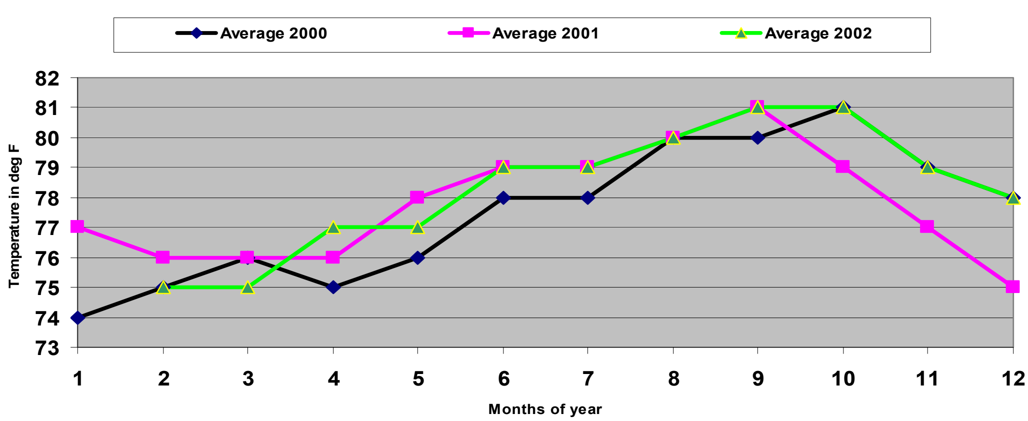


Figure 6.2: Average Temperatures of Surface Water 2000-2002
(Courtesy of HECO - Kahe Power Station Data)

Similarly, the bathymetry measured off the West Beach area indicates that this region of Oahu possesses an amenable access to cold water resources approaching the desired 4°C required to maximize energy output of the Kalina Cycle® in this application (see Figure 6.3 below). These depths (approximately 3000 feet or 1000 meters) can be reached within approximately 7 km (4.3 miles) from shore which is within the limits of current technology for cold water pipe design and deployment.

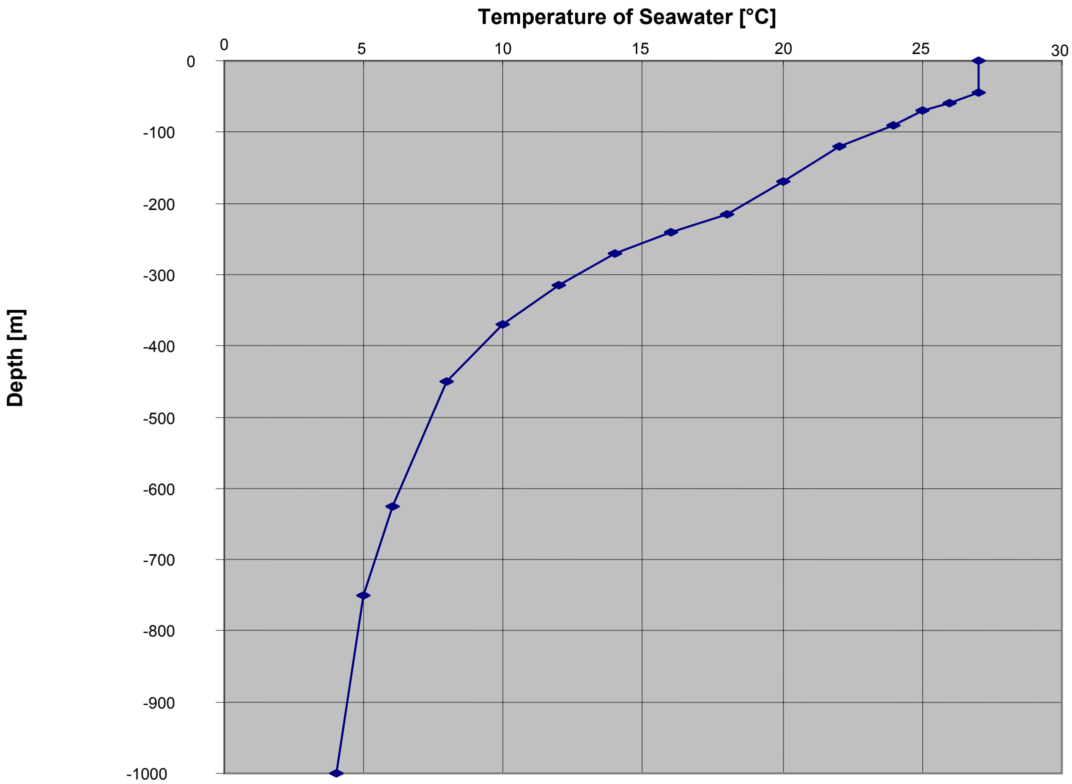


Figure 6.3: Typical Tropical Ocean Temperature Profile
(Courtesy of Makai Ocean Engineering – West Beach Study)

6.2 10 MW_e Kalina Cycle® OTEC Design

A 10 MW_e Kalina Cycle® OTEC design has been prepared utilizing thermal resources consistent with what can be expected in the State of Hawaii as previously described in Section 6.1. Recurrent Resources, LLC, patent holders of the Kalina Cycle® technology, performed the optimized thermodynamic design presented. The following figure shows the optimized power system with relevant state points as defined in Table 6.1 below.

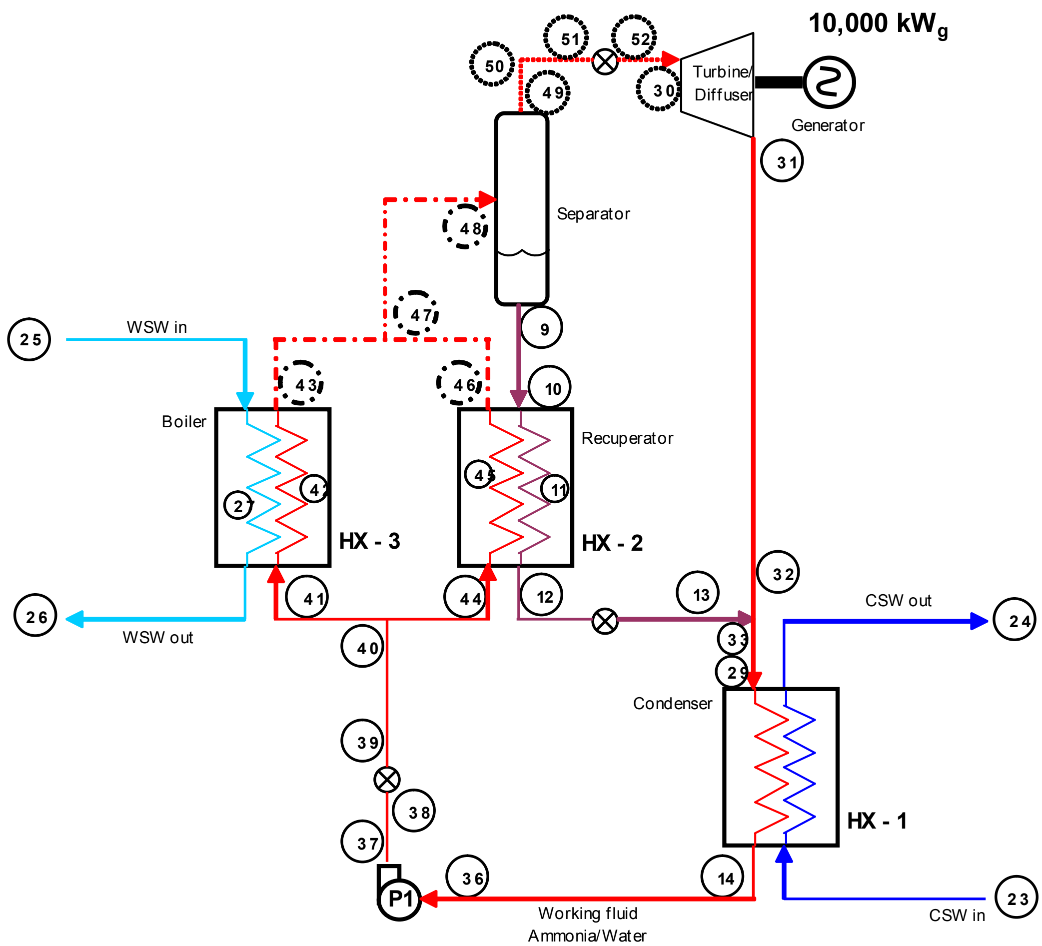


Figure 6.4: Kalina Cycle® Power System Flow Diagram w/State Points

TABLE 6.1: KALINA CYCLE® POWER SYSTEM - STATE POINTS

State Point	Description	P kPa *[psia]*	T °C *[°F]*	m kg/s *[lb/hr]*	h kJ/kg *[Btu/lb]*	X	Phase
9	Ammonia separator outlet	**588.70**	**22.95**	**600.41**	**-103.69**	**0.6812**	**sat liquid**
		85.38	*73.31*	*4,765,190.0*	*-44.62*		*ammonia/water*
10	Recuperator inlet	**585.20**	**22.79**	**600.41**	**-103.69**	**0.6812**	**wet 0.9994**
	(separator stream)	*84.88*	*73.02*	*4,765,190.0*	*-44.62*		*ammonia/water*
11	Recuperator working	**564.50**	**18.39**	**600.41**	**-125.37**	**0.6812**	**liquid 2°**
	parameters (separator stream)	*81.87*	*65.10*	*4,765,190.0*	*-53.95*		*ammonia/water*
12	Recuperator outlet	**557.60**	**17.88**	**600.41**	**-127.78**	**0.6812**	**liquid 2°**
	(separator stream)	*80.87*	*64.18*	*4,765,190.0*	*-54.98*		*ammonia/water*
13	Recuperator outlet joining	**442.20**	**14.64**	**600.41**	**-127.78**	**0.6812**	**wet 0.983**
	Turbine outlet for condensation	*64.14*	*58.35*	*4,765,190.0*	*-54.98*		*ammonia/water*
14	Condenser outlet (working fluid)	**435.30**	**6.78**	**967.00**	**-114.65**	**0.8020**	**sat liquid**
		63.13	*44.20*	*7,674,629.7*	*-49.33*		
23	Condenser inlet (cold seawater)	**–**	**4.00**	**16,862.95**	**16.75**	**Water**	
		–	*39.20*	*133,833,806.5*	*7.21*		*cold seawater*
24	Condenser outlet (cold seawater)	**–**	**11.13**	**16,862.95**	**46.62**	**Water**	
		–	*52.03*	*133,833,806.5*	*20.06*		*cold seawater*
25	Evaporator inlet (warm seawater)	**–**	**26.00**	**16,773.04**	**103.90**	**Brine**	
		–	*78.80*	*133,120,230.4*	*44.71*		*warm seawater*
26	Evaporator outlet (warm seawater)	**–**	**18.33**	**16,773.04**	**73.27**	**Brine**	
		–	*64.99*	*133,120,230.4*	*31.53*		*warm seawater*
27	Evaporator conditions	**–**	**18.95**	**16,773.04**	**75.72**	**Brine**	
	(warm seawater)	–	*66.11*	*133,120,230.4*	*32.58*		*warm seawater*
29	Condenser inlet (working fluid)	**442.20**	**14.45**	**967.00**	**406.27**	**0.8020**	**wet 0.7525**
		64.14	*58.01*	*7,674,629.7*	*174.81*		*ammonia/water*
30	Turbine inlet	**586.10**	**22.88**	**366.59**	**1309.68**	**0.9998**	**vapor 0°**
		85.01	*73.18*	*2,909,439.7*	*563.54*		*ammonia/water*
31	Turbine/Diffuser exhaust	**444.40**	**8.11**	**366.59**	**1280.97**	**0.9998**	**wet 0.0008**
		64.45	*46.60*	*2,909,439.7*	*551.19*		*ammonia/water*
32	Turbine exhaust joining recuperator outlet for	**442.20**	**8.03**	**366.59**	**1280.97**	**0.9998**	**wet 0.0008**
	condensation	*64.14*	*46.45*	*2,909,439.7*	*551.19*		*ammonia/water*

State Point	Description	P kPa [psia]	T °C [°F]	m kg/s [lb/hr]	h kJ/kg [Btu/lb]	X	Phase
33	Turbine exhaust/recuperator outlet	**442.20** *64.14*	**14.45** *58.01*	**967.00** *7,674,629.7*	**406.27** *174.81*	**0.8020**	**wet 0.7525** *ammonia/water*
36	Working fluid to feed pump	**435.30** *63.13*	**6.78** *44.20*	**967.00** *7,674,629.7*	**-114.65** *-49.33*	**0.8020**	**sat liquid** *ammonia/water*
37	Working fluid after feed pump	**646.60** *93.78*	**6.82** *44.28*	**967.00** *7,674,629.7*	**-114.28** *-49.17*	**0.8020**	**liquid 20°** *ammonia/water*

TABLE 6.1: KALINA CYCLE® POWER SYSTEM - STATE POINTS *(Continued)*

State Point	Description	P kPa [psia]	T °C [°F]	m kg/s [lb/hr]	h kJ/kg [Btu/lb]	X	Phase
38	Working fluid prior to valve	**644.50** *93.48*	**6.82** *44.28*	**967.00** *7,674,629.7*	**-114.28** *-49.17*	**0.8020**	**liquid 20°** *ammonia/water*
39	Working fluid after valve	**610.00** *88.47*	**6.83** *44.29*	**967.00** *7,674,629.7*	**-114.28** *-49.17*	**0.8020**	**liquid 17°** *ammonia/water*
40	Working fluid feed to evaporator and recuperator	**609.40** *88.39*	**6.83** *44.29*	**967.00** *7,674,629.7*	**-114.28** *-49.17*	**0.8020**	**liquid 17°** *ammonia/water*
41	Working fluid inlet to evaporator	**605.90** *87.88*	**6.83** *44.29*	**934.13** *7,413,802.6*	**-114.28** *-49.17*	**0.8020**	**liquid 16°** *ammonia/water*
42	Working fluid in evaporator	**600.40** *87.08*	**16.17** *61.11*	**934.13** *7,413,802.6*	**-70.21** *-30.21*	**0.8020**	**sat liquid** *ammonia/water*
43	Working fluid exiting evaporator	**592.10** *85.88*	**23.22** *73.80*	**934.13** *7,413,802.6*	**435.86** *187.55*	**0.8020**	**wet 0.7588** *ammonia/water*
44	Working fluid entering recuperator	**605.90** *87.88*	**6.83** *44.29*	**32.86** *260,827.1*	**-114.28** *-49.17*	**0.8020**	**liquid 16°** *ammonia/water*
45	Working fluid in recuperator	**600.40** *87.08*	**16.17** *61.11*	**32.86** *260,827.1*	**-70.21** *-30.21*	**0.8020**	**sat liquid** *ammonia/water*
46	Working fluid exiting recuperator	**592.10** *85.88*	**20.56** *69.01*	**32.86** *260,827.1*	**325.77** *140.18*	**0.8020**	**wet 0.8566** *ammonia/water*
47	Working fluid mixture from recuperator and evaporator	**588.70** *85.38*	**22.95** *73.31*	**967.00** *7,674,629.7*	**432.11** *185.93*	**0.8020**	**wet 0.7626** *ammonia/water*
48	Working fluid into separator	**588.70** *85.38*	**22.95** *73.31*	**967.00** *7,674,629.7*	**432.11** *185.93*	**0.8020**	**wet 0.7626** *ammonia/water*
49	Ammonia vapor leaving separator	**588.70** *85.38*	**22.95** *73.31*	**366.59** *2,909,439.7*	**1309.68** *563.54*	**0.9998**	**sat vapor** *ammonia/water*

50	Ammonia vapor to turbine	**587.70**	**22.93**	**366.59**	**1309.68**	**0.9998**	**wet 0**
		85.24	*73.27*	*2,909,439.7*	*563.54*		*ammonia/water*
51	Ammonia vapor prior to steam valve	**587.20**	**22.91**	**366.59**	**1309.68**	**0.9998**	**sat vapor**
		85.17	*73.24*	*2,909,439.7*	*563.54*		*ammonia/water*
52	Ammonia vapor after steam valve	**586.10**	**22.88**	**366.59**	**1309.68**	**0.9998**	**vapor 0°**
		85.01	*73.18*	*2,909,439.7*	*563.54*		*ammonia/water*

TABLE 6.2: KALINA CYCLE® POWER SYSTEM - SYSTEM SUMMARY

Turbine mass flow	**366.59**	kg/s	*2,909,464*	*lb/hr*
Point 30 volume flow	**84,379.17**	l/s	*10,727,361*	*ft^3/hr*
Point 31 volume flow	**106,229.06**	l/s	*13,505,198*	*ft^3/hr*
Heat in	**513,897.50**	kW	*531.44*	*kJ/kg*
Heat rejected	**503,730.95**	kW	*520.92*	*kJ/kg*
ΣTurbine enthalpy drops	**10,526.32**	kW	*10.89*	*kJ/kg*
Turbine Work	**10,000.00**	kW	*10.34*	*kJ/kg*
Feed pump ΔH power (37)	**382.25**	kW	*0.40*	*kJ/kg*
Feed + coolant pump power	**1,777.29**	kW	*1.84*	*kJ/kg*
Net work	**8,222.71**	kW	*8.50*	*kJ/kg*
Gross Output	**10,000.00**	kW_e		
Cycle Output	**9,617.74**	kW_e		
Net Output	**8,222.71**	kW_e		
Net thermal efficiency	**1.6**	%		
Second law limit	**4.96**	%		
Second law efficiency	**32.27**	%		
Specific WW consumption	**7,343.51**	kg/kW-hr	*16,189.50*	*lb/kW-hr*
Specific Power Output	**0.136**	Watt-hr/kg	*0.06*	*Watt-hr/lb*

TABLE 6.3: KALINA CYCLE® SYSTEM - HEAT EXCHANGER SUMMARY

	MW_{th}	Streams	ΔT's (°C)
Heat Exchanger - 1	503.731	T29 - T24	3.31
		T14 - T23	2.78
Heat Exchanger - 2	14.462	T10 - T46	2.22
		T11 - T45	2.22
		T12 - T44	11.05
Heat Exchanger - 3	513.897	T25 - T43	2.78
		T27 - T42	2.78
		T26 - T41	11.5

TABLE 6.4: KALINA CYCLE® SYSTEM - PRESSURE DROP SUMMARY

	Streams	ΔP (kPa)	*ΔP (psi)*
Heat Exchanger Pressure Drops	P23 - P24	62.05	*9.0*
	P29 - P14	6.89	*1.0*
	P41 - P42	5.52	*0.8*
	P42 - P43	8.27	*1.2*
	P10 - P11	20.68	*3.0*
	P38 - P39	34.47	*5.0*
	P11 - P12	6.89	*1.0*
	P - SCV	0.01	*0.0019*
Auxiliary Pressure Drops	P32 - P13	0.00	*0*
	P13 - P33	0.00	*0*
	P33 - P29	0.00	*0*
	P14 - P36	0.00	*0*
	P9 - P10	3.45	*0.5*
	P25 - P27	39.99	*5.8*
	P27 - P26	22.06	*3.2*
	P37 - P38	2.07	*0.3*
	P39 - P40	0.69	*0.1*
	P40 - P41	3.45	*0.5*
	P40 - P44	3.45	*0.5*
	P43 - P47	3.45	*0.5*

	P46 - P47	**3.45**	*0.5*
	P47 - P48	**0.00**	*0*
	P48 - P50	**0.97**	*0.14*
	P50 - P51	**0.55**	*0.08*
	P52 - P30	**0.00**	*0*
	P31 - P32	**2.21**	*0.32*
	P44 - P45	**5.52**	*0.8*
	P45 - P46	**8.27**	*1.2*

6.2.1 Kalina Cycle® Process Equipment and Cost

The process equipment for a Kalina Cycle® OTEC system presented below will be nearly identical to the equipment needed for a geothermal process (only sized differently to accommodate more amenable thermal resources and subsequently smaller flows – hence the lower anticipated installed capacity costs per kW-hr) and modified only slightly for all other applications as determined by ammonia/water mixture ratios and system temperatures and flows. Applications incorporating the Kalina Cycle® for exploiting flue gas waste heat will necessarily require additional components to accommodate the differing heat source mediums. The necessary primary system components are as follows:

Vapor Turbine: The vapor turbine in this application would be a standard design “steam” turbine. Generally, a single-stage radial flow Curtis wheel design with two rows of blades is used. The wheel is an overhung (cantilever) design with an integral gear on the shaft. The overhung design eliminates the need to preheat the turbine prior to start-up, allowing rapid starts. This design also requires only one seal, thus reducing losses of the ammonia-water vapor. This type turbine has proven very applicable to geothermal process application and is anticipated to perform similarly under OTEC conditions. The gear is used to couple the turbine to a 1,500 rpm TEWAC synchronous generator. Nitrogen is used as the sealing, or “buffer,” gas medium to the gas-lubricated mechanical turbine seal. A nitrogen generator provides a continuous supply of sealing gas.

Heat Exchangers: The evaporator is anticipated to be a shell-and-tube exchanger utilizing titanium tubes. The recuperator is a carbon steel shell-and-tube exchanger. The condenser is a plate-type heat exchanger with welded pairs on the ammonia-water process side to minimize leakage. Plates are titanium to provide corrosion protection in contact with seawater.

Separator: the separator is an impingement-type vane module. The vanes are composed of stainless steel corrugated profile plates assembled with phase separating chambers. The separator module is mounted inside a pressure vessel with an integral liquid reservoir.

Process Pumps: The pumps in the cycle are vertical turbine pumps designed to handle saturated ammonia-water liquid. The pumps are fitted with tandem mechanical seals.

Building: All equipment is housed indoors. The powerhouse footprint is approximately a compact 50 x 80 meters [164 x 262 feet]. This area includes laydown and access aisles.

Cost: Total cost for the proposed Kalina Cycle OTEC facility, excluding ocean piping system is approximately \$30 million (~ \$3,000/kW_g). Addition of the piping costs, necessary for a complete analysis, would add an additional \$30 – 40 million; however, additional co-products (i.e., fresh water production, air conditioning, aquaculture, cold water agriculture etc.) utilizing the same water resources would necessarily be added to the development of such a project and would provide additional revenue streams to offset the initial capital costs. Considering the relative ease of automation of the process and non-existent fuel costs, operational and maintenance costs for such a facility would be extremely low in comparison to other power production systems (~ \$1 – 1.5 million per year).

7.0 PROPOSED MARKETING PLAN

The most promising applications of the Kalina Cycle® for electrical power generation in Hawaii are:

1. As OTEC (at the shoreline or floating offshore),
2. As a second stage in the geothermal plant (Puna Geothermal) on the Big Island of Hawaii,
3. As a bottoms cycle using the waste heat from a conventional power plant (at Kahe for example).

Marketing and financing such installations would involve different approaches and different participants in each of these three applications of the Kalina Cycle®. This will be discussed further below.

As all three of these technologies would produce consistent, reliable, base-load power the fee structure for wholesale purchase of the produced electricity should closely follow that currently employed for the Puna Geothermal power facility. Namely, the independent power producer should be provided an “avoided cost” compensation (presently about 6¢/kWh on Oahu) in conjunction with a capacity credit as well. The capacity credit is an accounting measure which rewards independent power producers for providing consistent, rather than intermittent power so that the local power authority (HECO, HELCO, MECO) doesn't have to maintain additional "back-up" capacity to offset "down times" generally experienced in other more intermittent renewable technologies (i.e., wind, photovoltaics, etc.). Such a fee structure for these technologies will require PUC approval - but is essential to make a viable marketing plan and financial arrangement for Kalina Cycle® applications.

7.1 Potential Financing Mechanisms

Potential financing mechanisms for each Kalina Cycle® application considered economically viable for implementation in Hawaii are broken down in the following sections.

7.1.1 OTEC Applications

The primary large scale application of OTEC being considered here is a 100 MW offshore structure that would be located off Barbers Point, Oahu. The structure would use the existing technology developed by the oil companies for deep drilling at depths greater than 1000 meters. Power would be produced using the Kalina Cycle® and transmitted to the grid via submarine cable. Marketing such a plant would be to Federal, State and local governmental agencies to reach compliance with requirements to have a significant percentage of their electrical power supplied from renewable sources. Marketing would also be aimed at HECO to substitute a 100 MW OTEC facility for their proposed new coal fired plant to meet growth in demand. Probably the best approach to finance, build and operate such a facility would be a public-private venture with participation by HECO, U.S. Navy, State and local governmental entities and one or more private companies. Financing would then be through government bonds, bank loans and debts. The fuel is "free" and operation and maintenance are minimal.

Other possible OTEC installations in Hawaii may or may not involve the Kalina Cycle®. These are likely to be smaller shore-based units with a variety of other products (in addition to power) including fresh water, air conditioning, ice, aquaculture and agriculture. The marketing and financial aspects of these potential installations are very site specific. In these and other cases being considered here the best way to approach marketing and financing is to consider the costs and revenues over the entire project life (usually taken as 30 years) in comparison to providing the same services using a fossil fuel based system over the same 30 year period.

7.1.2 Second Stage Geothermal Plant at Puna

The objective of a second stage plant using the Kalina Cycle® is to squeeze a few more megawatts out of the hot fluids being discharged by the conventional geothermal plant. Kalina Cycle® plants elsewhere are already operational under just such circumstances. Marketing such a plant to Puna Geothermal Ventures, the existing geothermal company, the county and State of Hawaii and other interested parties should not be difficult since it would have no additional environmental effects and would reduce the need for further capacity. A similar group could be involved in a public-private venture and in providing the financing through a combination of government bonds, bank loans and private investment.

7.1.3 Power Plant Waste Heat Bottoms Cycle

A similar motivation exists to use the waste heat from a conventional power plant as was the case with the geothermal plant – to squeeze a few extra megawatts from the power cycle. In the case of a conventional power facility, it is generally the flue or stack gas which possesses the waste heat to be harnessed. Marketing this application will be a little more difficult as HECO has raised the concern that their existing facilities are already too limited in space to accommodate additional Kalina Cycle® equipment. However these concerns can be greatly alleviated through configuring the Kalina Cycle® vertically, instead of horizontally, so as to not require additional floor space. This should increase the interest of HECO for considering addition of the Kalina Cycle® to their existing facilities as an environmentally responsible alternative for increasing plant efficiencies and power output.

In the case of the cooling water waste heat of a conventional plant, however, the difference in temperatures available between cooling tower discharge and ambient seawater are too small for Kalina Cycle® application and may be more advantageously utilized as a heat supplement to the operation of an OTEC plant. This was proposed in the early 1980's for Kahe (but subsequently dropped due to the sudden fall in oil prices and rise in interest rates). A more detailed evaluation is required now to determine the optimum design for using that waste heat.

In any case, these scenarios are another example where a public-private venture involving HECO, governmental agencies and private companies would be the preferred vehicle to design, finance, build, and operate such a plant. The outcome of these activities would be more efficient use of our resources in an environmentally sound and economical manner.

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APPENDIX A: INNOVATIVE ENERGY WORKSHOP SUMMARY

Summary of Events:

The Innovative Energy Systems Workshop was a successful informational and interactive forum for participants and presenters alike on the advancements and potential commercial applications for Seawater Air Conditioning (SWAC) and Kalina Cycle® applications in Hawaii.

The first day of the workshop, Wednesday March 19, 2003, focused on the potential for commercial SWAC implementation in Hawaii as a follow-up to recommendations outlined in the DBEDT report *Seawater District Cooling Feasibility Analysis for the State of Hawaii*, October 2002. A broad range of experience and technical expertise was encompassed by the speakers, as well as a significant level of familiarity with the topic displayed by the more than 70 workshop attendees. Many pertinent questions and informed concerns were addressed in the panel discussions following each session.

The second day of the workshop, Thursday March 20, 2003, entailed two varying topics. The morning session focused on the Kalina Cycle® technology and its potential applications with particular emphasis for Hawaii. The afternoon sessions provided a forum for workshop participants to provide feedback and suggestions towards implementing and actualizing the proposed energy systems into commercial applications in Hawaii.

The format and content of the workshop was viewed by nearly all participants as extremely informative and beneficial as an informational exchange forum. Overall success of the workshop will be determined by the level of commercialization of the discussed technologies in Hawaii over the next few years. Many of the participants of the workshop expressed their recognition of Hawaii's unique opportunity, and therefore, responsibility, to embrace renewable technologies such as SWAC and the Kalina Cycle® effectively leveraging Hawaii's most abundant natural resource, the tropical ocean.

A detailed report of the workshop activities focusing on the Kalina Cycle® technology follows. (Detailed information on the SWAC technology can be found in an independent report prepared by The Cool Solutions Company).

Day 1 – Wednesday March 19, 2003 – Morning Session

Session 1: District Cooling and Deep Water Air Conditioning

Welcome and Opening Comments
Dr. David Rezachek, P.E., Alternate Energy Specialist – State of Hawaii – DBEDT

Dr. Rezachek provided a brief welcome and overview of the day's scheduled presentations and discussions.

District Cooling Systems – An Overview
Mr. Jack Kattner, CEO – FVB Energy, Inc.

For Details of this presentation, see The Cool Solutions Company independent summary of this workshop.

Project Financing for District Energy Systems
Mr. Scott Blumeyer, President - Norventus Group, LLC

For Details of this presentation, see The Cool Solutions Company independent summary of this workshop.

Seawater Air Conditioning (SWAC), Cold Water Pipe Design, and a Brief Overview of Toronto Lake Source Cooling Project
Dr. Joe Van Ryzin, P.E., President – Makai Ocean Engineering, Inc.

For Details of this presentation, see The Cool Solutions Company independent summary of this workshop.

Cornell Lake Source Cooling Project
Mr. W.S. (Lanny) Joyce, P.E., Manager of Engineering, Planning and Energy Management – Cornell University

For Details of this presentation, see The Cool Solutions Company independent summary of this workshop.

Panel Discussion No. 1 – Identify Barriers to Implementation in Hawaii
Kattner, Blumeyer, Van Ryzin, Joyce and Anders Rydaker, President – District Energy of St. Paul (DESP)
Moderator: Andrepont

For Details of this presentation, see The Cool Solutions Company independent summary of this workshop.

Lunch – Two Videos Presented on Cornell Lake Source Cooling Project (Cornell Univ.)

The two videos were:
(1) Promotional video summarizing projects benefits
(2) Construction footage of project development through entire project

Day 1 – Wednesday March 19, 2003 – Afternoon Session

Session 2: District Cooling, SWAC, and SWAC/TES Hybrids for Hawaii

Basics of Plate Heat Exchangers
Ms. Elizabeth Wheeler, Sr. Application Engineer – Invensys APV

For Details of this presentation, see The Cool Solutions Company independent summary of this workshop.

Downtown Honolulu Ice Storage/District Cooling Project
Mr. Jack Kattner, CEO – FVB Energy, Inc.

For Details of this presentation, see The Cool Solutions Company independent summary of this workshop.

Results of the Hawaii SWAC Feasibility Analysis
Dr. David Rezachek, P.E., Alternate Energy Specialist – State of Hawaii – DBEDT

For Details of this presentation, see The Cool Solutions Company independent summary of this workshop.

Preliminary Results of the SWAC/TES Project
Mr. John Andrepont, President – The Cool Solutions Company

For Details of this presentation, see The Cool Solutions Company independent summary of this workshop.

Overview of a Successful Public-Private Partnership (PPP) District Energy System
Mr. Anders Rydaker, President – District Energy St. Paul (DESP)

For Details of this presentation, see The Cool Solutions Company independent summary of this workshop.

Panel Discussion No. 2 – Overcoming Barriers to Implementation
Wheeler, Rezachek, Kattner, Andrepont, Rydaker
Moderator: Van Ryzin

For Details of this presentation, see The Cool Solutions Company independent summary of this workshop.

Day 2 – Thursday March 20, 2003 – Morning Session

Session 3: Waste Heat, The Kalina Cycle®, and Kalina Cycle® Applications in Hawaii

Welcome and Opening Comments
Dr. David Rezachek, P.E., Alternate Energy Specialist – State of Hawaii – DBEDT

Dr. Rezachek provided a brief welcome and overview of the day's scheduled presentations and discussions.

The Kalina Cycle – Description and Applications
Mr. Yakov Lerner, VP of Engineering & Projects – Recurrent Resources, LLC

Mr. Lerner provided a brief introduction to the Kalina Cycle® technology and introduced the basic engineering concepts from which the cycle derives its efficiency improvements over the traditional Rankine Cycle. He also provides a brief case study history of the Husavik, Iceland geothermal Kalina Cycle® facility constructed and operating since July '00.

- Recurrent Resources, LLC is the world-wide licensee of the Kalina Cycle®
  - The Kalina Cycle® is breakthrough technology providing higher levels of performance than have been impossible to attain with traditional steam plants. It reduces the cost of power and decreases pollutant emissions by making power plants more efficient.
  - This technology makes geothermal power competitive with all other new base-load generation technologies.
  - Exergy holds over 250 world-wide patents on the Kalina Cycle®
- Advantages of Kalina Cycle® power plants
  - Higher plant efficiency
  - Lower generation costs (less fuel, lower O&M costs)
  - Reduced emissions
  - Less energy to heat working fluid
  - Less fuel consumption in process
  - More energy recuperation
  - Lower cost of electricity per kilowatt-hour
- Kalina Cycle® provides significant power efficiency improvements over Rankine cycles for low temperature (100° – 1000° F) waste heat sources
  - Greatest performance enhancement at lower temperatures (~100°F)
- Waste heat can be most efficiently recovered to produce electrical energy using the Kalina Cycle®
  - Areas of application
    - Waste heat recovery in industry

        - Gas compressor stations
        - Iron & Steel industry
        - Cement industry
        - Chemical industry
        - Incineration plants
        - Diesel plants
    - Hot brine heat recuperation
        - Geothermal plants
- Kalina Cycle® is better than the Rankine Cycle because:
    - Ammonia/water working fluid
    - Vary the mixture of working fluid throughout the cycle
    - Captures more thermal energy for generating electricity
    - Higher level of recuperation
    - Result: More kilowatt hours of output per unit of fuel input or cycle heat input
- Key advantages of the Kalina Cycle®
    - Structural process – no technical or component improvements required
        - Improved heat transfer
        - Improved recuperation
        - Reliance on proven plant components
    - Exploitation of an additional degree of freedom
        - Composition changes within the power cycle similar to refrigeration plants
    - Capital cost is less than Rankine cycle
- Kalina Cycle®: Inherent advantages
    - Improved heat transfer from hot to cold streams
        - Key: Mixture boils at a variable temperature
        - Closer temperature profile between heat transfer streams means improved efficiency
- Kalina Cycle® comparison
    - Geothermal heat acquisition comparison
        - Kalina vs. ORC (Organic Rankine Cycle)
        - The water/ammonia working fluid more closely replicates the thermal resource in a counter flow heat exchanger over isopentane and other organic working fluids
- Kalina vs. ORC efficiency comparison
    - Kalina is 30-80% more efficient (higher efficiency at lower resource temperatures)
- Thermodynamic relationships of the Kalina Cycle® are well-known and documented
- The Kalina Cycle® components are well-known and off-the-shelf
- Commercial examples of Kalina Cycle® applications:
    - Sumitomo Metals, Tokyo, Japan
        - Configuration: Waste heat

    - Customer: Sumitomo Steel
    - Construction site: Tokyo, Japan
    - Electrical output: 3.1 MW
    - Commissioned: July '99
  - Husavik Power Plant, Husavik, Iceland
    - Configuration: Geothermal
    - Customer: Municipality – Husavik
    - Construction site: Husavik, Iceland
    - Electrical output: 2.0 MW
    - Commissioned: July '00
- Innovative cascaded use
  - Electrical power
  - Spent brine used for heating
  - Cooling water reused as well
- Commercial history of the Husavik-Kalina Cycle® plant
  - Bids from a number of binary cycle suppliers were submitted in 1999
  - Bid awarded to Exergy in 1999: 2 MW for $1,874,000 or $905/kW
  - Plant officially started up and entered service July 22, 2000
  - Plant performance tests in November 2001, after 15 months of operation
- The first year of operation for Husavik plant
  - Proven, stable operation
  - Output was lower than design output due to lower resource temperature
  - The separator caused problems; after the 2000-2001 peak winter season, this was fixed
  - Some equipment received mechanical erosion and pluggage resulting from poor chemical cleaning during commissioning
    - Separator screen
    - Turbine flow path
    - Feed pump
  - Plant demonstrated high reliability
  - It happily operates largely unattended
  - It proved to be quiet, sturdy and not smelly at all
  - Performance testing completed November 28 & 29, 2001, corrected net power output of 1959 kW to 2060 kW
- Kalina Cycle® configuration and components diagram shown
- Kalina Cycle® "waste heat" potential in the U.S. & Canada
  - U.S. ~ 3602 MW
  - Canada ~ 1349 MW
- Canoga Park Demonstration project
  - Configuration: Combined cycle
  - Operator: Boeing
  - Construction site: California

  - Electrical output: 6.5 MW
  - Commissioned: June '92
  - Operational: 1992 - 1997
- What are the advantages of the Kalina Cycle® over ORC
  - Proven reference
  - Thermodynamics are known and practiced
  - Higher output for a given heat source
  - Lower specific capital cost ($/kW)
  - High degree of plant safety
  - Kalina Cycle® is BACT
  - Strong OEM partnerships
- Ammonia safety concerns
  - Needs to be used carefully
  - Less hazardously flammable than more conventional working fluids
  - Comparatively environmentally benign
  - Ammonia vents easily, and is self-alarming
  - Ammonia is the 6th largest chemical product in the U.S.
  - Proven safety record in ammonia synthesis, power plants and refrigeration plants
- Kalina Cycle® technology conclusions:
  - Commercially available
  - Underlying principals are simple
  - Effective and safe
  - Utilized in refrigeration for over 100 years
  - Breakthrough in:
    - Understanding ammonia/water properties
    - Applying to power plant operations
    - Developing proprietary super-efficient cycle designs

<u>Preliminary Results of the Hawaii Kalina Cycle® Feasibility Analysis</u>
Dr. Stephen K. Oney, Vice President - OCEES International, Inc.

Dr. Oney introduced the concepts of the Kalina Cycle® and its benefits over more traditional Rankine cycle systems. He also emphasized the unique advantages of the multiple working fluid concepts, particularly to low temperature, in waste heat recovery systems. Dr. Oney then addressed the potential waste heat sources initially identified in the *Hawaii Kalina Cycle® Feasibility Analysis* that OCEES is preparing for DBEDT. He provided some specific examples of promising potential applications and scenarios for Kalina Cycle® waste heat recovery in Hawaii.

- The Kalina Cycle®
  - Binary energy conversion cycle which uses ammonia/water mixture as the working fluid

  - Variable mixture (concentration changes throughout the cycle) which allows the working fluid to efficiently match the characteristics of the resource
    - Ideal for low temperature/bottoming cycle applications
- Ammonia/water safety concerns
  - Needs to be handled carefully
    - Not classified as hazardous
  - Less hazardously flammable than more conventional working fluids
  - Comparatively environmentally benign
  - Ammonia vents easily, is self-alarming
- Single working fluid thermodynamic limitation
  - Requires significant heat input to overcome change of state (i.e., liquid to vapor)
  - Binary working fluid allows for incremental increase in temperature for incremental addition of heat
- Simplified comparison of Rankine cycle to Kalina Cycle®
  - Similar components, but the Kalina Cycle® has a distillation/condensation sub-system (D/CSS) which the Rankine cycle does not
- There are several operational Kalina Cycle® plants with commercial experience
  - Canoga Park, California – 6.5 MW
  - Husavik, Iceland – 2.0 MW (geothermal)
  - Sumitomo Steel Factory – 3.5 MW (industrial waste heat)
- Husavik Geothermal Plant – “First two years”
  - Demonstrated high reliability (availability rate in the high 90%)
  - Operates successfully largely unattended
  - Proved quiet, sturdy with no odor
- Energy generation by source in Hawaii (1999)
  - Petroleum – 78%
  - Coal – 12%
  - Gas – 0.5%
  - Hydroelectric – 1.5%
  - Other (i.e., geothermal, wind, biomass, etc.) – 8%
- Ten largest power plants in Hawaii by generating capacity – 1999
  - Kahe – Petroleum – 582 MW - Oahu
  - Waiau – Petroleum – 457 MW - Oahu
  - Kalaeola Co-gen – Petroleum – 261 MW - Oahu
  - AES Hawaii – Coal – 189 MW - Oahu
  - Maalaea – Petroleum – 168 MW - Maui
  - Honolulu – Petroleum – 100 MW - Oahu
  - Port Allen – Petroleum – 97 MW - Kauai
  - H-Power – Waste – 61 MW - Oahu
  - Hawaiian Com & Sugar – Coal/biomass – 58 MW - Maui

  - W H Hill – Petroleum – 35 MW – Hawaii
- All forms of energy used for primary energy production in Hawaii have some form of waste heat – usually significant quantities
- How much waste heat in Hawaii?
  - ~ 9 billion kW-hr/year electricity from fossil fuels
  - Conservative estimate:
    - From stack gases: ~ 356 million kW-hr/year
    - From cooling water: ~ 534 million kW-hr/year
    - Total: ~ 890 million kW-hr/year (~10% of total energy production in Hawaii!)
  - Waste heat potential in Hawaii is quite significant
- Petroleum/Diesel Power Plants
  - Kahe Power Plant – Oahu
  - Maalea Power Plant – Maui
- Showed a simplified conceptual flow diagram for a diesel combined cycle
  - Heat recovery vapor generator for flue/hot gas
  - Distillation/condensation sub-system
  - Heat recovery vessel utilizing jacket water from engine cooling system
- Peak design capacity for diesel combined-cycle/bottoming cycle depends upon:
  - Diesel exhaust gas temperature and flow
  - Fuel sulfur content (limits the minimum stack temperature)
  - Type of cooling available (water or air cooled)
  - Capacity of diesel generating station
  - Site ambient conditions
  - Diesel back pressure requirements
  - Bottoming cycle design
- Design capacity comparison
  - First case study
    - Kohinoor Energy Ltd. – Pakistan
    - 8x Wartsila 18V46 diesel units
      - Existing Rankine bottoming cycle = ~ 8 MW_{net}
      - Initial Kalina Cycle® design = ~ 13.3 MW_{net} (+66%)
      - Optimized Kalina Cycle® design = ~ 16.0 MW_{net} (+100%)
  - Second case study
    - Kohinoor Energy Ltd. – India
    - 4x Wartsila 12V46 diesel units
      - Design Rankine bottoming cycle = ~ 1.87 MW_{net}
      - Kalina Cycle® design = ~ 3.24 MW_{net} (+66%)
- Case study example – Turkey - Basic assumptions
  - 100 MW capacity (PPA ~ 876 million kWh/yr)
  - Man B&W 18-V-48/60 diesel unit (18.39 MW each)
  - Three competing scenarios:

    - Scenario 1: 7 diesel generating units, no bottoming cycle, one diesel generating unit in standby
    - Scenario 2: 6 diesel generating units, no bottoming cycle, no diesel generating unit in standby
    - Scenario 3: 6 diesel generating units, Kalina bottoming cycle (11 MW), no diesel generating unit in standby
  - Capital costs
    - Diesel generation station ($650/kW)
    - Kalina cycle ($1200/kW)
  - O&M Costs
    - Diesel generation station ($0.01/kWh)
    - Kalina Cycle® ($0.005/kWh)
  - Fuel Costs ($0.20/kg)
- Case study summary
  - Total operating cost ($/yr)
    - Scenario 1: $41.22 million
    - Scenario 2: $39.25 million
    - Scenario 3: $37.78 million
  - Gross operating profit
    - Scenario 1: $15.72 million
    - Scenario 2: $15.05 million
    - Scenario 3: $19.16 million
  - Kalina Cycle® payback period
    - Scenario 1: 0.4 years
    - Scenario 2: 3.2 years
    - Scenario 3: --
  - Simple return on investment
    - Scenario 1: 18.8%
    - Scenario 2: 21.0%
    - Scenario 3: 22.5%
- Economics of bottoming cycles for large diesel generation stations
  - Capital costs:
    - Kalina Cycle® less than Rankine bottoming cycle ($/kW)
    - Kalina Cycle® more than diesel generation power plant
  - Savings in fuel cost more than makes up for additional capital
    - Savings on fuel is dependent upon fuel type
  - Include impact of standby diesel generation capacity for frequent diesel unit maintenance
- Economic viability of adding Kalina bottoming cycle to existing diesel generation station:
  - Size of the diesel station
  - Number and capacity of each diesel unit
  - Diesel unit annual average capacity factor
  - Diesel unit exhaust heat rejection

- Capital cost of the Kalina bottoming cycle power plant
- Avoided cost of energy (purchased energy tariff or cost of fuel and O&M)
- Kalina Cycle® power plant O&M
- Escalation assumptions
- Discount rate or cost of capital
- Debt assumptions
- Tax assumptions

- Other potential plants in Hawaii
  - Coal burning facilities
    - AES Hawaii, Inc. - Oahu
  - Biomass/waste power plants
    - Hawaiian Com & Sugar (Coal/biomass) – Maui
    - H-Power (waste) - Oahu
  - Large industrial facilities
    - Tesoro refinery - Oahu
  - Geothermal power plants
    - Puna Geothermal Venture – Hawaii
      - Showed schematic of existing Puna geothermal facility
      - Showed schematic of potential addition of Kalina Cycle system capturing waste heat from unused brine and condensate
- Husavik/Puna Resource Comparison
  - Husavik, Iceland Plant
    - Brine flow: 90 liters/sec @ 120° C
    - CW flow: 180 liters/sec @ 4° C
    - Power generated: 1.7 MW_{net}
    - Total cost: $1,875,000 ($905/kW)
  - Puna Geothermal Venture Plant
    - Brine flow: 189 liters/sec @ 149° C
    - CW flow: 85 liters/sec @ 40.6° C
  - Should the Puna Kalina Cycle® be air cooled or ocean water – design question!
- Other potential Kalina Cycle® applications for Hawaii
  - Could be used in conjunction with local power plants and future SWAC facilities to provide necessary pumping power for SWAC
  - Providing the power cycle for Ocean Thermal Energy Conversion applications
    - OTEC represents the greatest potential in Hawaii for Kalina Cycle® applications
- Predicted heat rate/efficiency gains by power plant technology
  - Geothermal plants
    - ~ 30 – 50% efficiency improvements
  - Coal/biomass/waste plants
    - ~ 20%

- Diesel/Petroleum plants
  - ~ 10 – 15%
- OTEC plants
  - ~ 50+%

- Conclusions:
  - The Kalina Cycle® is superior technology to traditional Rankine cycle of low temperature/bottoming cycle applications
  - Hawaii has significant waste heat resources for potential Kalina Cycle® integration
  - Integration of the Kalina Cycle® makes good environmental and economic sense under amenable conditions
  - Further analysis for specific identified applications is warranted

<u>On-Going Kalina Cycle® Developments</u>
Dr. Hans Jurgen Krock, P.E., President - OCEES International, Inc.

Dr. Krock focused on the implementation of the Kalina Cycle® and its adaptation as the preferred power system technology for integrated OTEC systems. He introduced the Workshop participants to the integrated, multi-product approach of OTEC systems currently being utilized by OCEES International, Inc. to commercialize OTEC globally in niche tropical island markets. He also outlined the potential for Kalina Cycle® based OTEC to function as the primary production mechanism for hydrogen in an impending hydrogen economy. The potential impact this could have on a future energy-exporting Hawaii economy was also presented.

- Bottoming cycle installations of the Kalina Cycle® exist in several locations under differing low temperature waste heat scenarios
  - Operational Kalina Cycle® plants
    - 6.5 MW Kalina Cycle® plant in Canoga Park, Ca.
    - 2 MW Kalina Cycle® plant in Husavik, Iceland
    - 3.5 MW Kalina Cycle® plant in Tokyo, Japan (Sumitomo Steel factory)
  - Each plant has excellent operational and performance records!
- Ocean Thermal Energy Conversion (OTEC) systems:
  - Economics work best in a niche market approach providing multi-product, optimized systems
  - Most efficient power cycle available for OTEC temperatures is the Kalina Cycle®
- OTEC utilizes the solar radiation incident upon and absorbed by the tropical ocean
  - Total human energy usage is equivalent to 0.005% of the total energy incident upon the earth's surface

  - Nearly 25% of the total solar energy incident upon the earth is absorbed by the tropical ocean
    - This represents the world's largest and most efficient solar energy collector on the planet
    - Utilizing this energy for total human consumption would still only represent 0.1% of the available energy which is within the noise of the natural system – humans could not begin to impact the system!
- Tropical ocean temperature profile
  - OTEC takes advantage of the same energy which drives the world's weather systems
    - Weather is driven by the temperature difference occurring between the tropical ocean and arctic oceans over thousands of miles
  - The same energy is available, vertically, over only 1 kilometer in the tropical ocean
    - The tropical ocean has a mixed surface layer (~ 100 meters) of "warm" water (~ 24 – 30° C)
    - The deep cold water is ~ 4 – 5° C at 1000+meter depths
- Hawaiian based research advances in OTEC over the past two decades
  - Cold water pipe design and installation
  - Open-cycle OTEC net power production
  - Closed-cycle OTEC demonstration facility
  - Bio-fouling control in warm water systems
  - Closed-cycle aluminum heat exchanger dynamics
  - Non-condensable gas exchange dynamics
  - Aquaculture development
  - Open-cycle OTEC fresh water production
- OTEC economics work best with an integrated multi-product approach in niche markets
  - OTEC power
    - Kalina Cycle® power system
    - Can be utilized through electrolysis to produce hydrogen
  - Desalinated water
    - Potable drinking water
    - Water for agriculture/industrial applications (irrigation)
  - Aquaculture
    - Finfish/shellfish
    - Micro-organisms/algae
    - Kelp, etc.
  - Cold water agriculture
    - Temporal crops available in tropical regions
    - Enhanced growing conditions/seasons
    - Additional irrigation potential utilizing natural humidity of air
  - Air conditioning
    - Building air conditioning (SWAC)

        - Process cooling for industrial facilities from plant effluent water
- Parameters required for a Kalina Cycle® OTEC design
    - Suitable temperature differential between warm water resource and cold water resource (~ 20° C)
    - Flow rates of resource water and temperatures
    - The chemical environment the Kalina Cycle® is expected to operate in (seawater, fresh water, etc.)
    - Elevation of plant above seawater
- Relevant technical developments over the last decade for OTEC commercialization
    - Operating Kalina Cycle® plants from which operational experience can be derived
    - Open-cycle OTEC pilot plant experience
    - Non-condensable gas problems solved
    - Commercial-scale cold water AC systems installed
    - Open-cycle OTEC turbine designs by reputable turbine manufacturers
    - Fresh water production with Open-cycle OTEC systems
    - Multi-product systems engineering
    - Existing oil drilling platforms in depths greater than 3000 feet
- Economic conditions are presently favorable for OTEC development
    - Interest rates at 40 year lows
    - Oil prices at or near all-time highs
        - This is especially true in niche markets
- OTEC's future
    - Large scale floating systems for power production and hydrogen production via electrolysis and liquefaction
    - Deep water offshore platforms have already been developed by the oil industry and are adaptable for OTEC applications
- Natural synergies for liquid hydrogen production via OTEC
    - Constant production rates
        - OTEC operates 24/7 without interruption or fluctuation
            - Provides maximum return on investment
    - Pure water resources
        - Pure distilled water required for electrolysis process
            - Fresh water easily produced in OTEC systems
    - Heat sink for liquefaction readily available
        - Efficient hydrogen liquefaction requires significant heat sink resource
            - Cold water provides this resource
    - Convenient transport to world-wide demand centers
        - OTEC in the tropical ocean already exists on the preferred transport medium for large-scale energy distribution – tanker transport across the oceans

    - Hydrogen can be produced much closer than current oil transport distances reducing distribution costs
    - Can be stored and transported utilizing existing technology
- Economics for hydrogen production via OTEC are favorable if coordinated with the oil industry
- For fair comparison between hydrogen and current transportation fuels, an economic analysis should include evaluation criteria comparing miles traveled rather than purely equivalent energy of fuel types as hydrogen fuel-cells provide significantly better efficiency in power-to-work conversions over conventional internal combustion engines
- The Kalina Cycle® is proven technology with a bright future in the development of the largest renewable resource in the world – the tropical ocean!

<u>Panel Discussion No. 3 – Kalina Cycle® Developments</u>
Lerner, Oney, and Krock
Moderator: Rezachek

This panel discussion was not performed as the presentations went longer than expected and an additional speaker was added. Several questions were posed the presenters at the conclusion of their talks and are addressed here in place of the Panel Discussion notes.

- Question: Can you explain the Uehara Cycle vs. Kalina Cycle®?
    - Uehara cycle is a modified Kalina Cycle® developed by Saga University in Japan after analyzing the Kalina Cycle® facility built in Tokyo for Sumitomo Steel
    - The Uehara Cycle utilizes an ammonia/water working fluid and essentially duplicates process equipment to avoid patent infringement concerns with the Kalina Cycle®
- Question: Of the scenarios outlined for Kalina Cycle® application in Hawaii, what are the most promising technologies?
    - For immediate implementation and benefit, probably the Puna Geothermal plant – Kalina Cycle® has excellent record in successful operation in conjunction with geothermal plants
    - Certainly, retrofitting some of the larger petroleum power plants for HECO as the Kalina Cycle® can be developed vertically in a plant to accommodate limited space availability
    - The most promising of all possible applications is the development of OTEC utilizing the Kalina Cycle® for the power cycle
- Question: How can Hawaii benefit from the development of OTEC?
    - If Hawaii were to develop the OTEC/SWAC industry, beyond merely exporting the technology as it now does, Hawaii could become a major energy exporter (hydrogen) thereby expanding its economic base

beyond tourism, providing high quality jobs, export revenues, and taxes

Deep Ocean Water Applications Facility
Dr. Manfred J. Zapka, Senior Project Director – Marc M. Siah & Associates

Dr. Zapka provided a brief overview of the Deep Ocean Water Applications facility (DOWA) project commissioned by the Honolulu Board of Water Supply in January 2003. The project, as described by Zapka, will entail an investigation of several scenarios for fresh water production utilizing various sea water desalination technologies. Included in the analysis is Open-cycle OTEC with single stage fresh water production, closed-cycle OTEC utilizing the Kalina Cycle® power system with parallel fresh water production, multi-stage flash evaporation (MSF), and MED technologies. The study will also investigate the integration of other co-products and services associated with the deep ocean water such as SWAC, process cooling, and aquaculture support. Seven sites across the Southern and Southwestern shores of Oahu have been initially identified as possible candidate locations for the project development. The project is currently at the very initial stages and is expected to last through the remainder of 2003.

Lunch – "District Energy is the Link" (provided by the IDEA)

The short promotional video provided insight into the benefits of District Energy to its customers, environment (emissions reduction), and energy efficiency for the serviced district. It also provided information regarding the present growth rate and extent of the District Energy industry in the United States and Canada.

Day 2 – Thursday March 20, 2003 – Afternoon Session

Session 4: Workshop Feedback

Panel Discussion No. 4 – Facility Owner-Operator Feedback
Workshop attendees representing Hawaiian facilities (Mr. Kevin Saito – Utilities Manager, US Navy PHNSY Energy Services Division; Mr. Gary Shimabukuro – Acting Energy Manager, US Navy PHNSY & IMF; and representative of the State of Hawaii DAGS, managing a $3 million/yr energy budget for downtown Honolulu area State buildings)
Moderator: Andrepont

For Details of this panel discussion, see The Cool Solutions Company independent summary of this workshop.

Panel Discussion No. 5 – Recommended Next Step for Realization
All workshop participants
Moderator: Andrepont

For Details of this panel discussion, see The Cool Solutions Company independent summary of this workshop.